EMPLOYING AN EFFECTIVENESS MODEL FOR CALCULATING COOLING TOWER PERFORMANCE

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LIST OF ABBREVIATIONS

A_v - surface area of water droplets per volume of cooling tower

C_{pa} - constant pressure specific heat of moist air

C_{pw} - constant pressure specific heat of liquid water

C_s - derivative of saturation air enthalpy with respect to temperature

h_a - enthalpy of moist air per mass of dry air

h_C - convection heat transfer coefficient

h_D - diffusion mass transfer coefficient

h_g - enthalpy of water above reference state for liquid water at T_{ref}

h_s - enthalpy of saturated air

m_w - mass flow rate of water

m_a - mass flow rate of air

m^* - ratio of air flow rate to water effective capacitance rate for effectiveness analysis

Le - Lewis number

Ntu - overall number of transfer units

Q - actual heat transfer rate

T_{ref} - reference temperature for zero enthalpy of liquid water (32 °F)

T_w - water temperature

V - volume

e_a - air-side heat transfer effectiveness

w_a - air humidity ratio

w_s - humidity ratio of saturated air

Additional Subscripts

a - air stream conditions

i - inlet state conditions

o - outlet state conditions

T - total

w - water stream conditions

SUMMARY

Optimization of the design of chiller/cooling tower systems for large office buildings require an accurate detailed model for the cooling tower. This model must be precise and allow for varying air and water flow rates, ambient air conditions and entering water temperatures. The optimization computational requirement is very time consuming, however, due to the tower model requiring solution of three simultaneous differential equations.

The purpose of this project was to develop a computer program utilizing an effectiveness model to reduce computational time while maintaining good correlation to existing programs. The methodology involved the use of a tower model program developed by Eric Weber [1988] and the modifications made unto by Thane Joyce [1990] that integrated a centrifugal chiller model, cooling tower model, and system optimization strategy. The effectiveness model generated by James Braun [1988] was utilized in place of Weber's tower model.

The results are very encouraging. The computational time required to optimize the design was reduce approximately 75% while maintaining an accuracy of tower water temperature range of approximately 15%. This reduction in computer time will allow an engineer the flexibility to examine many systems and determine the optimum design in a shorter time frame.

INTRODUCTION

The design of heating, ventilation and air conditioning (HVAC) for large buildings tasks the engineer with manipulating a plethora of design parameters. With limitations on funding and typically a short fused deadline, engineers rely on rule-of-thumb or past experience when designing these systems. No attempt is made to optimize the system as a unit bringing together all component parts: pumps, chiller, cooling tower, pipe size, etc.

An optimization methodology for the chiller/cooling tower system was developed by Thane Joyce. The results of his work show that an optimized system can save both construction and operating costs. The computational requirements to perform the optimization, however, is very time consuming and therefore the methodology was not applicable as a design tool. In order to make the program more useful, the computational time needed to be reduced. This is accomplished by employing Braun's effectiveness model in lieu of the Weber cooling model in Joyce's program. The resulting program was then compared to the original Joyce program for accuracy and reduction in computational time.

DEVELOPMENT OF EFFECTIVENESS COMPUTER MODEL

The effectiveness model used to replace the tower model developed by Weber is based on the work by James Braun. A schematic of a counterflow cooling tower is provided in figure 1.

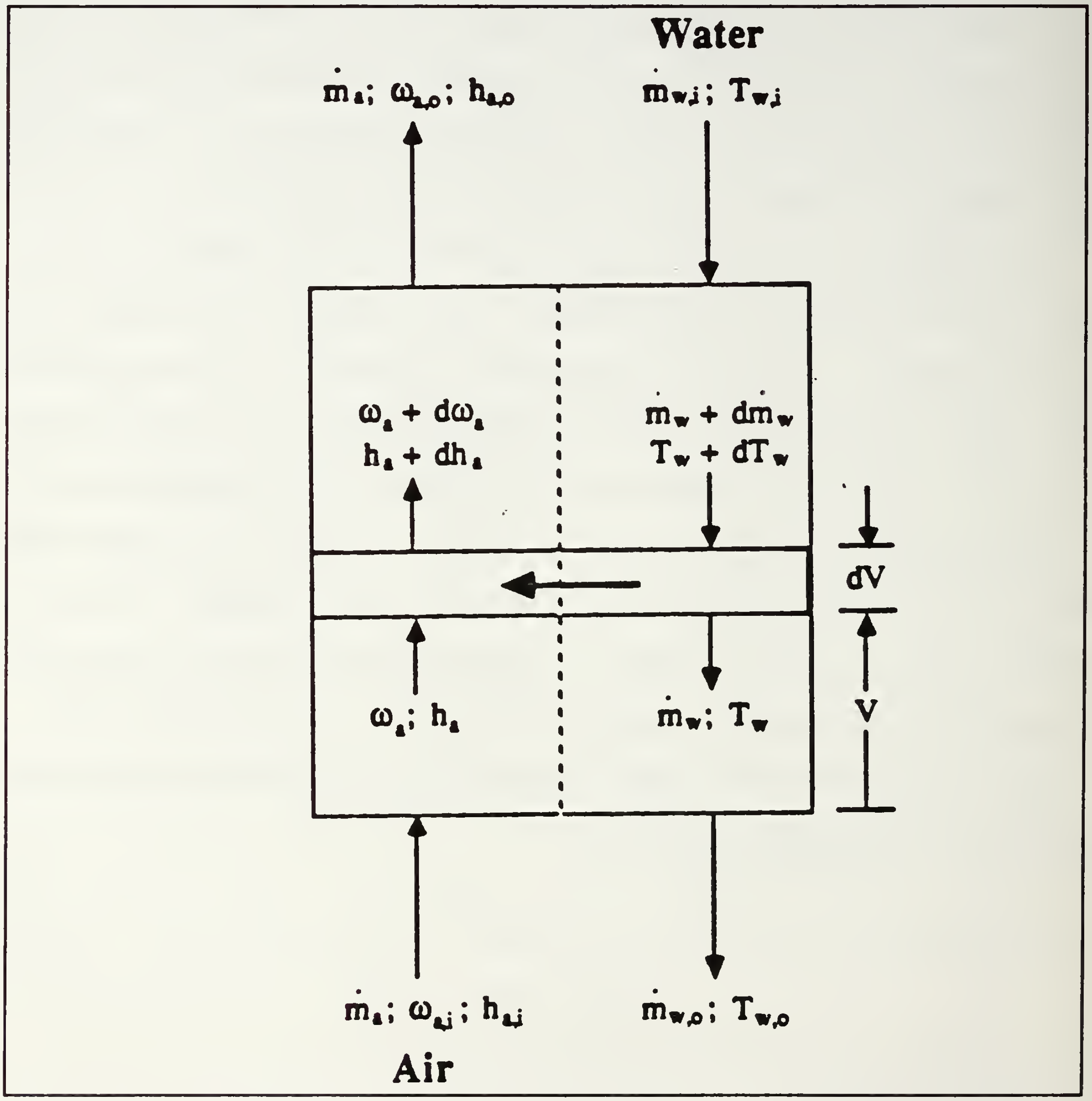

Figure 1. Schematic of a Counterflow Cooling Tower [Braun, 1988]

The following assumptions were made by Braun to derive the basic model equations:

1. Heat and mass transfer in the direction normal to flows only.
2. Negligible heat and mass transfer through tower walls to environment.
3. Negligible heat transfer from the tower fans to the air or water streams.
4. Constant water and dry air specific heats.
5. The mass fraction of water vapor in the mixture of air and vapor is approximately equal to the humidity ratio.
6. Uniform temperature throughout the water stream at any cross section.
7. Uniform cross-sectional area of the tower.

From steady-state energy and mass balances on an incremental volume, refer to figure 1, the following differential equations are developed by Braun and Weber:

$$\frac{d\omega_a}{dV} = -\frac{Ntu}{V_T}(\omega_a - \omega_{s,w}) \tag{1}$$

$$\frac{dh_a}{dV} = -\frac{Le\,Ntu}{V_T}\left[(h_a - h_{s,w}) + (\omega_a - \omega_{s,w})\left(\frac{1}{Le} - 1\right)h_{g,w}\right] \tag{2}$$

$$\frac{dT_w}{dV} = \frac{\frac{dh_a}{dV} - C_{pw}(T_w - T_{ref})\frac{d\omega_a}{dV}}{\left[\frac{\dot{m}_{w,i}}{\dot{m}_a} - (\omega_{a,o} - \omega_a)\right]C_{pw}} \tag{3}$$

where

$$Le = \frac{h_c}{h_D C_{pa}}$$

$$Ntu = \frac{h_D A_V V_T}{\dot{m}_a}$$

Knowing the inlet conditions, the number of transfer units, and the Lewis number, the exit state of both the air and water streams can be determined. Using these same equations, Weber took an iterative approach with respect to the outlet humidity ratio and the exit water temperature, numerically integrating the equations over the entire volume from air inlet to outlet.

The effectiveness model simplifies this analysis considerably. By employing Merkel's assumptions of neglecting water loss and setting the Lewis number equal to unity, the three differential equations reduce to:

$$\frac{dh_a}{dV} = -\frac{Ntu}{V_T}(h_a - h_{s,w}) \tag{4}$$

$$\frac{dT_w}{dV} = \frac{\dot{m}_a (dh_a/dV)}{\dot{m}_w C_{pw}} \tag{5}$$

Equation (5) can be written in terms of air enthalpies only by introducing a new variable, C_s, termed the saturation specific heat:

$$\frac{dh_{s,w}}{dV} = \frac{\dot{m}_a C_s (dh_a/dV)}{\dot{m}_w C_{pw}} \tag{6}$$

where

$$C_s = [\frac{dh_s}{dT}]_{T=T_w} \qquad (7)$$

C_s is equivalent to the derivative of the saturated air enthalpy with respect to temperature evaluated at the water temperature and has the units of specific heat. Braun indicates that if the saturation air enthalpy were linear with respect to temperature then the exit conditions could be solved for analytically. His figure 2, shown below, depicts the variation of the saturation enthalpy with temperature for typical water inlet and outlet points along with a straight line connecting the points.

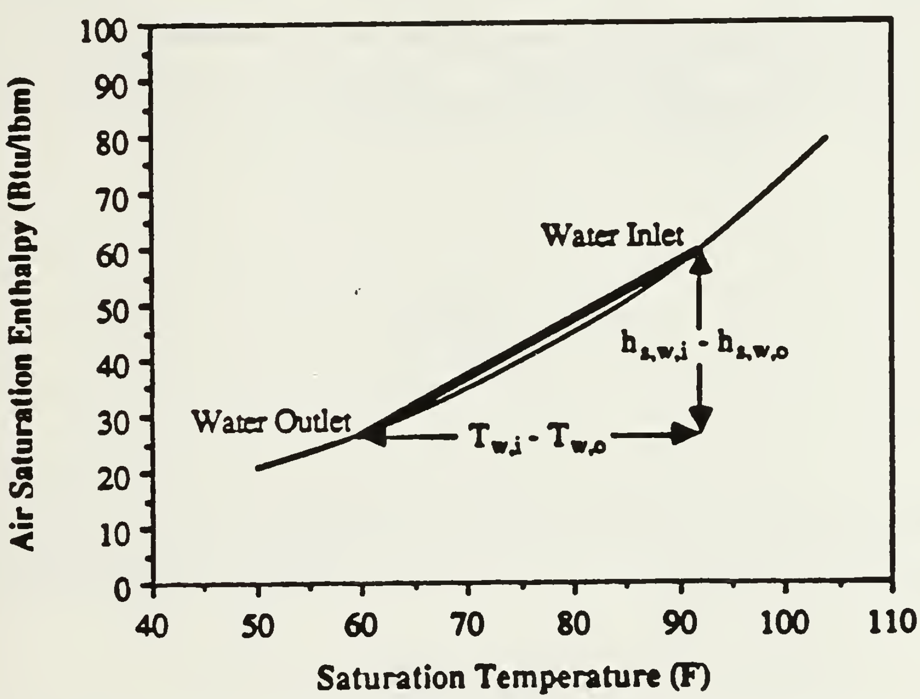

Figure 2. Saturation Air Enthalpy versus Temperature [Braun, 1988]

It is clear form the figure that the saturation air enthalpy does not vary linearly with temperature, however, by choosing an appropriate average slope between the inlet and outlet states, an air-side effectiveness relationship in terms of C_s can be developed. This air-side effectiveness is defined as the ratio of the actual heat transfer to the maximum possible heat transfer if the exiting air were saturated at the temperature of the incoming water (i.e., $h_{a,o} = h_{s,w,i}$).

Writing the heat transfer in terms of this effectiveness yields:

$$\dot{Q} = \epsilon_a \dot{m}_a (h_{s,wi} - h_{ai}) \tag{8}$$

where

$$\epsilon_a = \text{air-side heat transfer effectiveness}$$
$$= \frac{1 - exp(-Ntu(1 - m^*))}{1 - m^* exp(-Ntu(1 - m^*))} \tag{9}$$

and

$$m^* = \frac{\dot{m}_a}{\dot{m}_{w,i}(C_{pw}/C_s)} \tag{10}$$

The average value for the saturation specific heat is estimated as the average slope between the inlet and outlet state points:

$$C_s = \frac{h_{s,w,i} - h_{s,w,o}}{T_{w,i} - T_{w,o}} \tag{11}$$

The outlet air enthalpy and water temperature can then be calculated using the following equations:

$$h_{a,o} = h_{a,i} + \epsilon_a (h_{s,w,i} - h_{a,i}) \tag{12}$$

$$T_{w,o} = \frac{\dot{m}_{w,i}\,(T_{w,i} - T_{ref})\,C_{pw} - \dot{m}_a\,(h_{a,o} - h_{a,i})}{\dot{m}_{w,o}\,C_{pw}} + T_{ref} \tag{13}$$

In the computer model employing the air-side effectiveness, the water loss is neglected, so $m_{w,i}$ is set equal to $m_{w,o}$. Since C_s depends upon $T_{w,o}$, the solution for the exit conditions is iterative using equations 9 through 13. The saturation specific heat, C_s, is only weakly dependent upon $T_{w,o}$, however, so any reasonable initial guess for $T_{w,o}$ (such as the inlet wet bulb temperature of the air) typically results in convergence in only two iterations.

CONCLUSIONS

The results of this exercise are very promising. The computational time savings for the effectiveness method was as much as 83% over the Joyce method, while the percent error in calculating the energy consumed was less than 14% for all cases.

The first portion of the project is dedicated to evaluating the affect of employing the effectiveness model on the delta temperature across a counterflow cooling tower. Weber's computer program is used to generate the control data set. The revised program generated the test data set. Figure 3 displays the results of this evaluation. Numerical data is found in Appendix B.

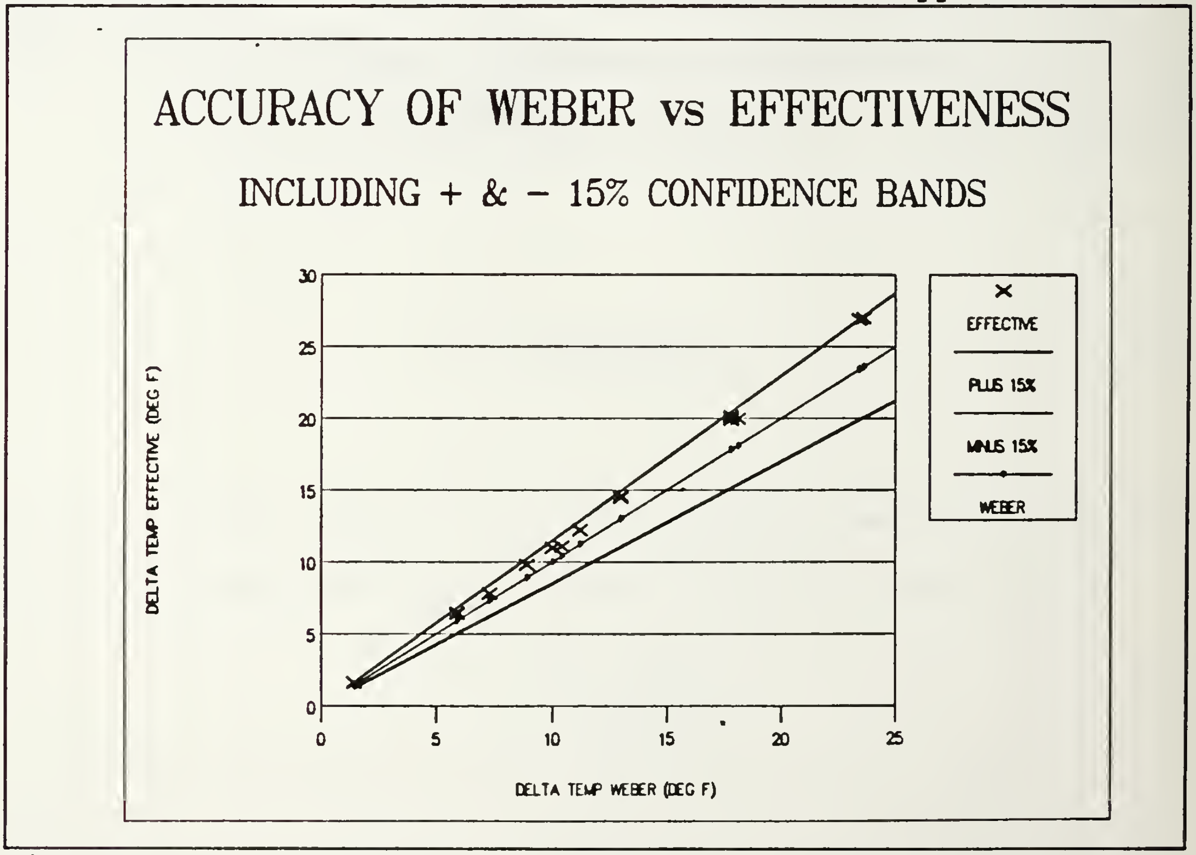

Figure 3. Accuracy of Weber versus Effectiveness Model

The effectiveness model computer program is provided as Appendix A. This model gives a larger delta temperature across the cooling tower in all cases compared with the exact data set. One reason why the effectiveness model overpredicts the tower delta temperature is that Weber's model is developed for a crossflow cooling tower while Braun's analysis is for a counterflow cooling tower. If improved accuracy in calculating the delta temperature across the tower is desired, a crossflow correction factor can be applied to the effectiveness model. Linearization of saturation enthalpy between the inlet and outlet points tends to overpredict the tower heat transfer and is another factor contributing to this error.

To test and compare the effectiveness model to the Weber cooling tower model in Joyce's program, several variables are manipulated while holding others constant. The variables investigated are: 1) air flow rate through tower (cfm), 2) tower size, and 3) pump size (gpm). These variables are considered the primary parameters for designing cooling towers. Figures 4 through 9 show the results of the comparisons for these various parameters. The results are encouraging and in each case the trends for both models are similar. Appendix C contains the numerical data used in generating these figures.

Figure 4 depicts the plot of effectiveness data versus Joyce data for various air flow rates through the cooling tower (CFM). The trends in both computational methods for this design parameter are very similar.

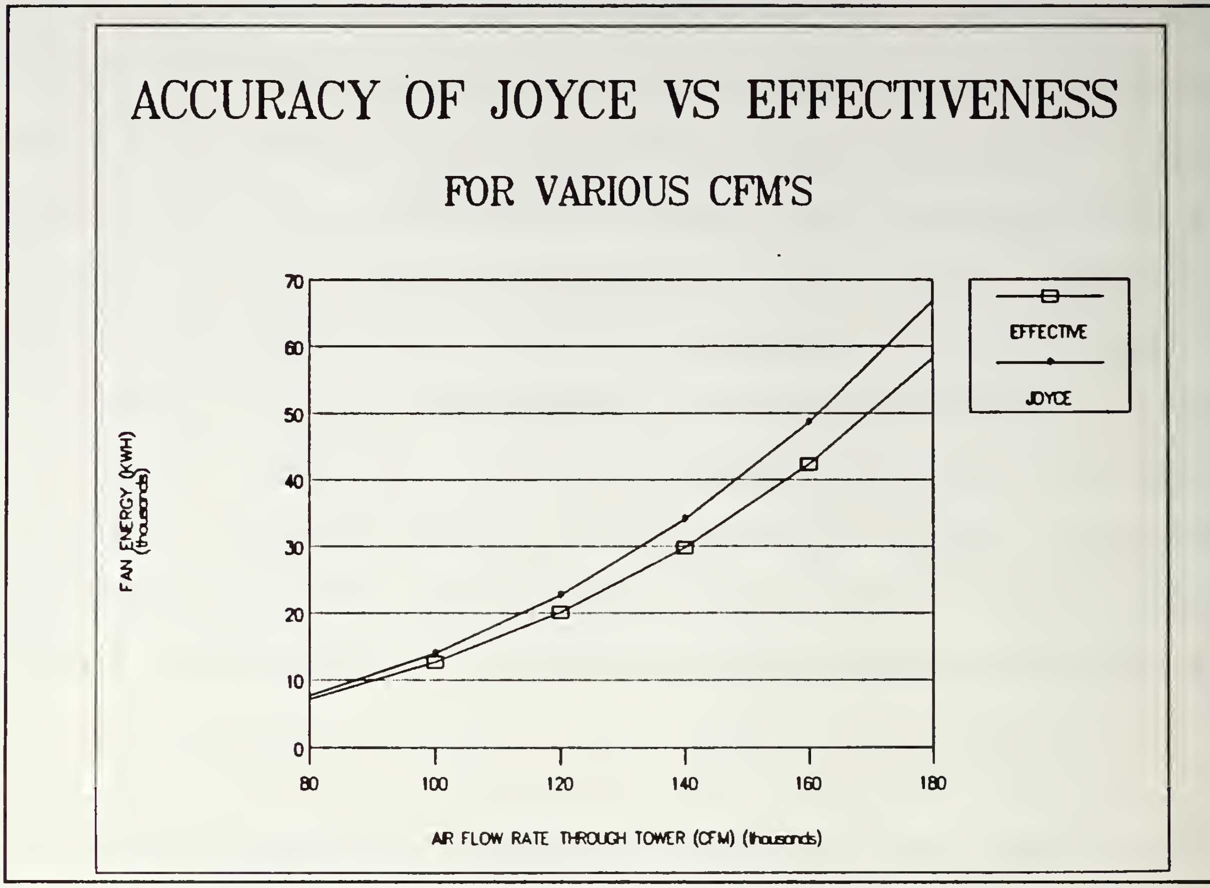

Figure 4. Plot of Effectiveness versus Joyce Data for Various CFMs.

The time savings for this variable are substantial, as shown in figure 5.

Six different tower air flow rates were used while holding the other variables constant. The maximum error, of 12.8%, occurs at a flow rate of 160000 CFM. The time savings are between 33 and 37 minutes, or roughly 81% improvement over the more exact Joyce model.

The next variable manipulated is tower size. Actual manufacture's performance data for Baltimore Aircoil series 3000 is used as input parameters. The results are very favorable giving

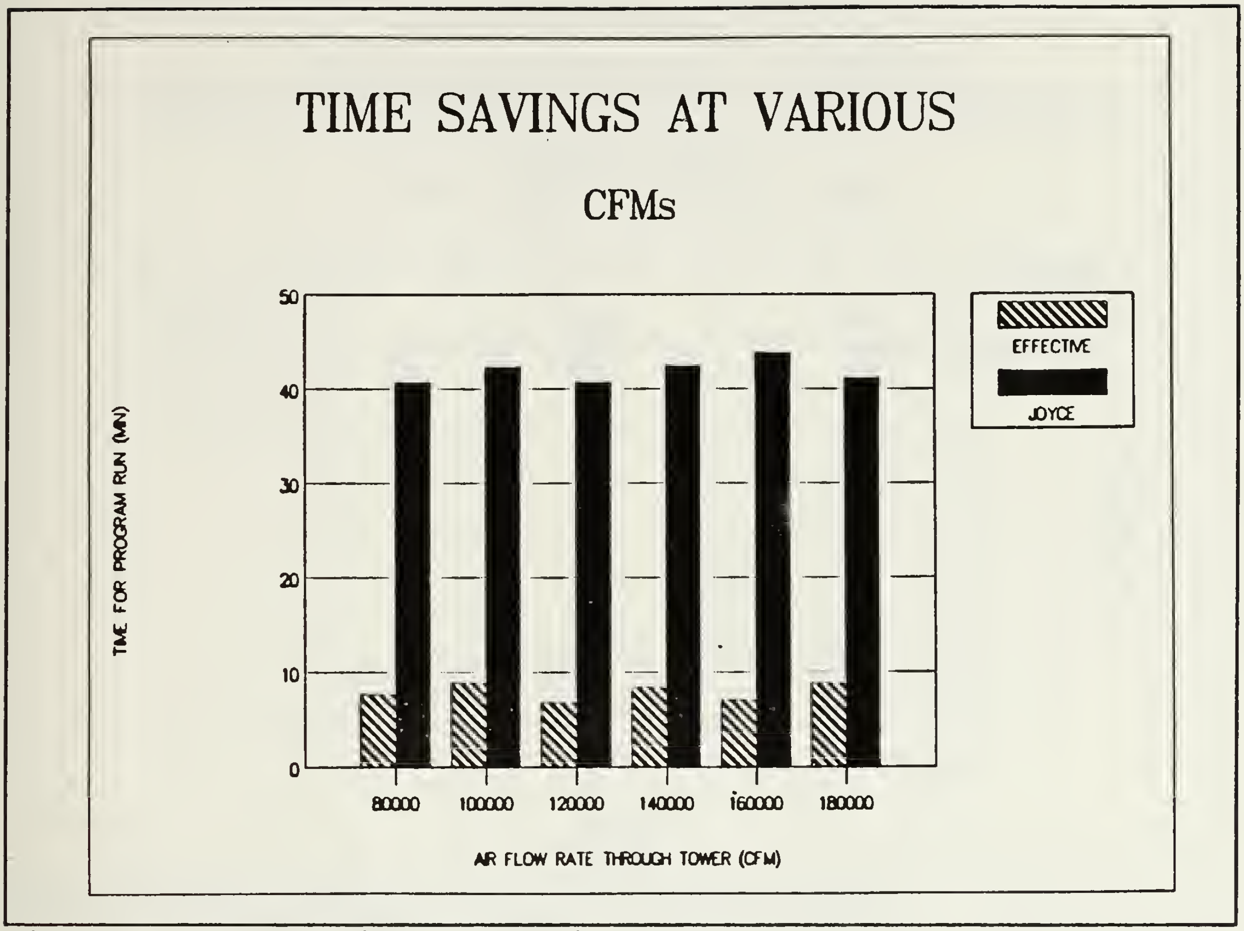

Figure 5. Time Savings at Various CFMs.

similar trends for both models, figure 6. The time savings using the effectiveness model over the Joyce method for this parameter are also quite impressive, refer to figure 7.

Six different tower sizes were used in the analysis. The effectiveness model underpredicts the tower fan energy used in all cases. The largest error, 13.7%, is found at tower number 19 which denotes a Baltimore Aircoil, series 3000, model number 3269. Savings in computational time is very impressive for this test variable. Approximately 34 minutes of saved time is seen for all cases, roughly an 80% improvement in computational run time.

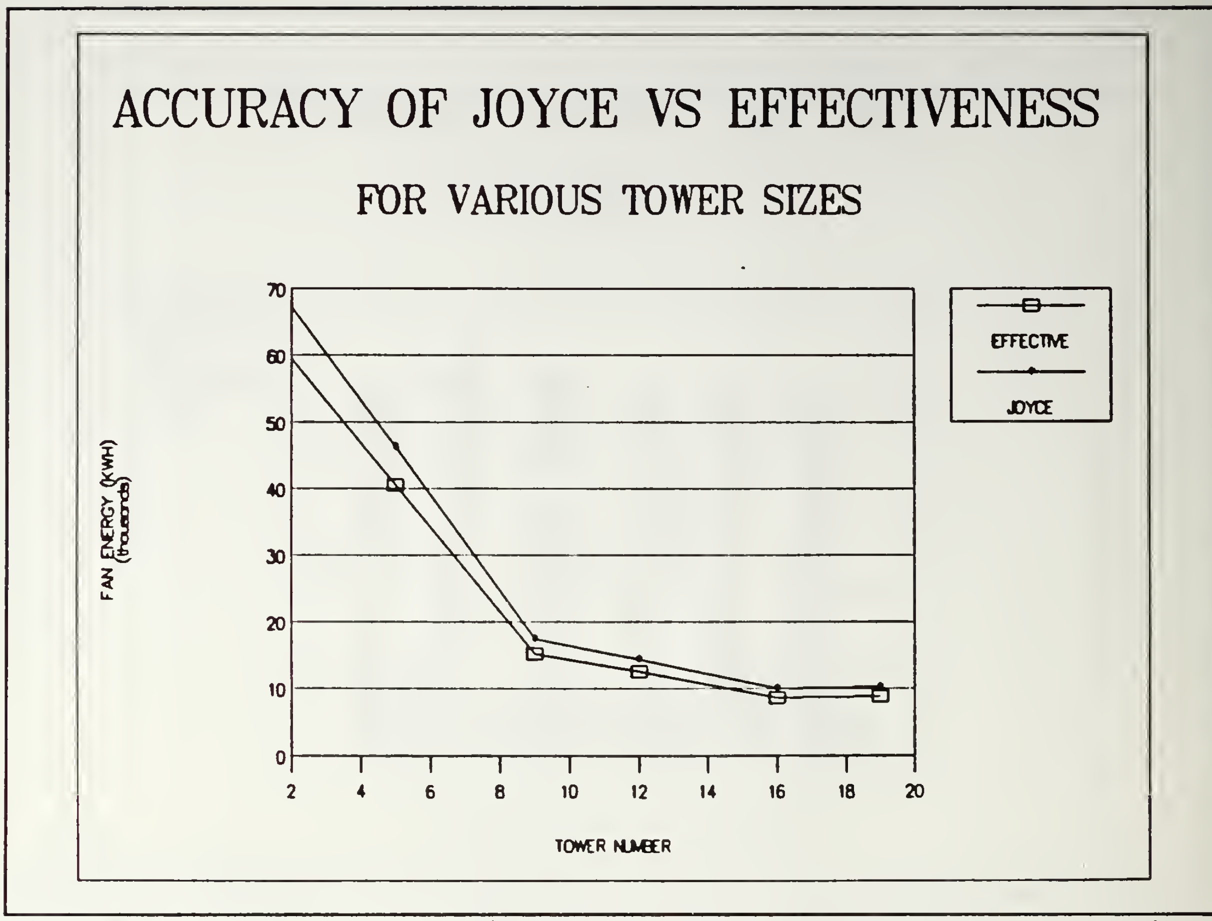

Figure 6. Plot of Effectiveness versus Joyce Data for Various Tower Sizes.

The final variable manipulated is condenser water pump size. Pump sizes between 750 GPM and 1500 GPM were used and the affect on both fan and pump energy (KWH) were tabulated. The results are promising, producing like trends for both the effectiveness model and Joyce method, refer to figure 8. Computational run time savings are also favorable for this parameter. Figure 9 presents the time savings for the new program as compared with the existing program for various pump sizes.

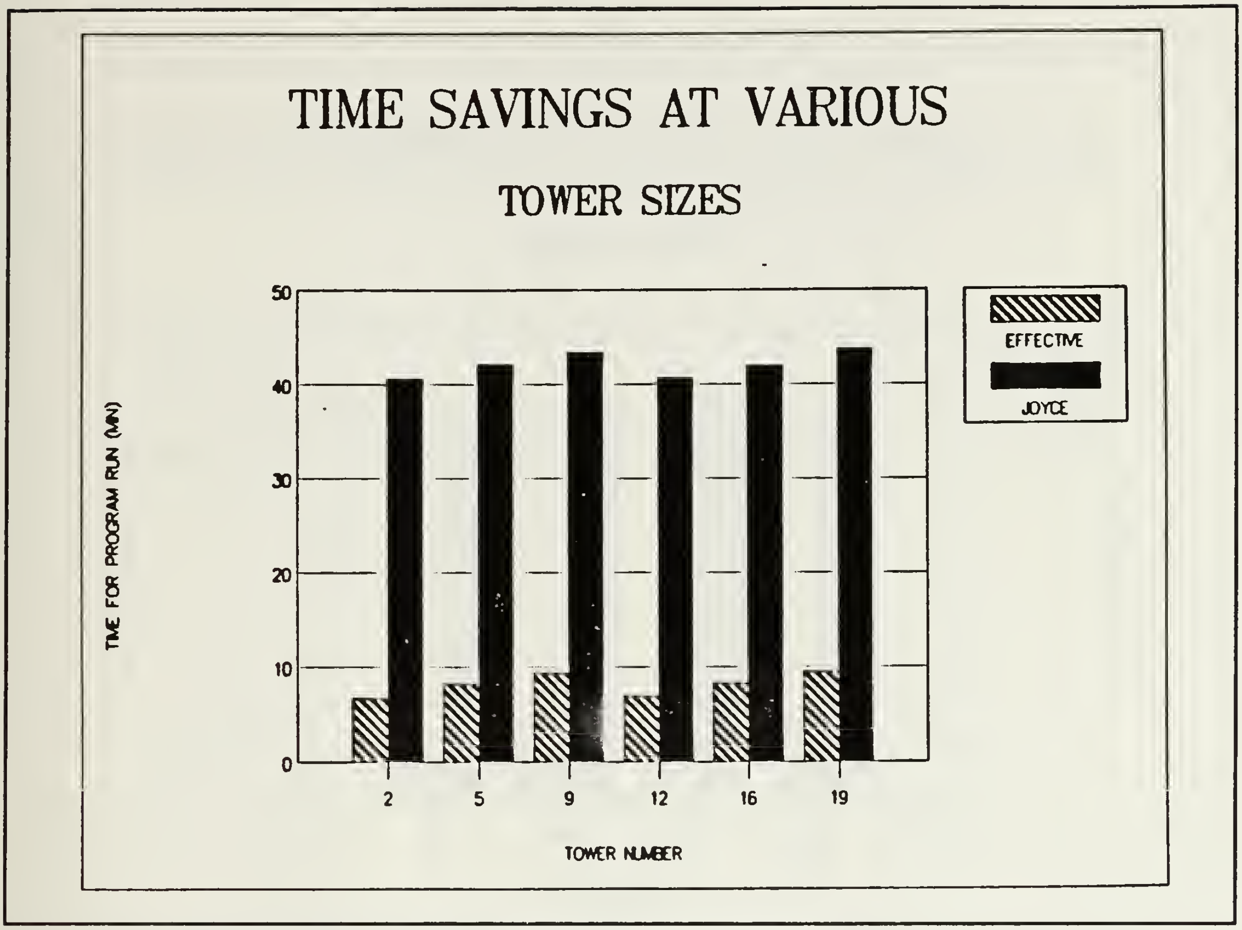

Figure 7. Time Savings at Various Tower Sizes

Again the effectiveness model underpredicts the fan and pump energy as compared to the Joyce method in all cases. The trends for both models, however, are very similar giving the same minimum and maximum point. The maximum error is roughly 10% and occurs at a pump size of 1000 GPM. Computer run time savings is very impressive at approximately 34 minutes or 81% as compared to the control data program.

As is shown in all the figures, the trends for both the effectiveness model and the Weber model in Joyce's program are very similar.

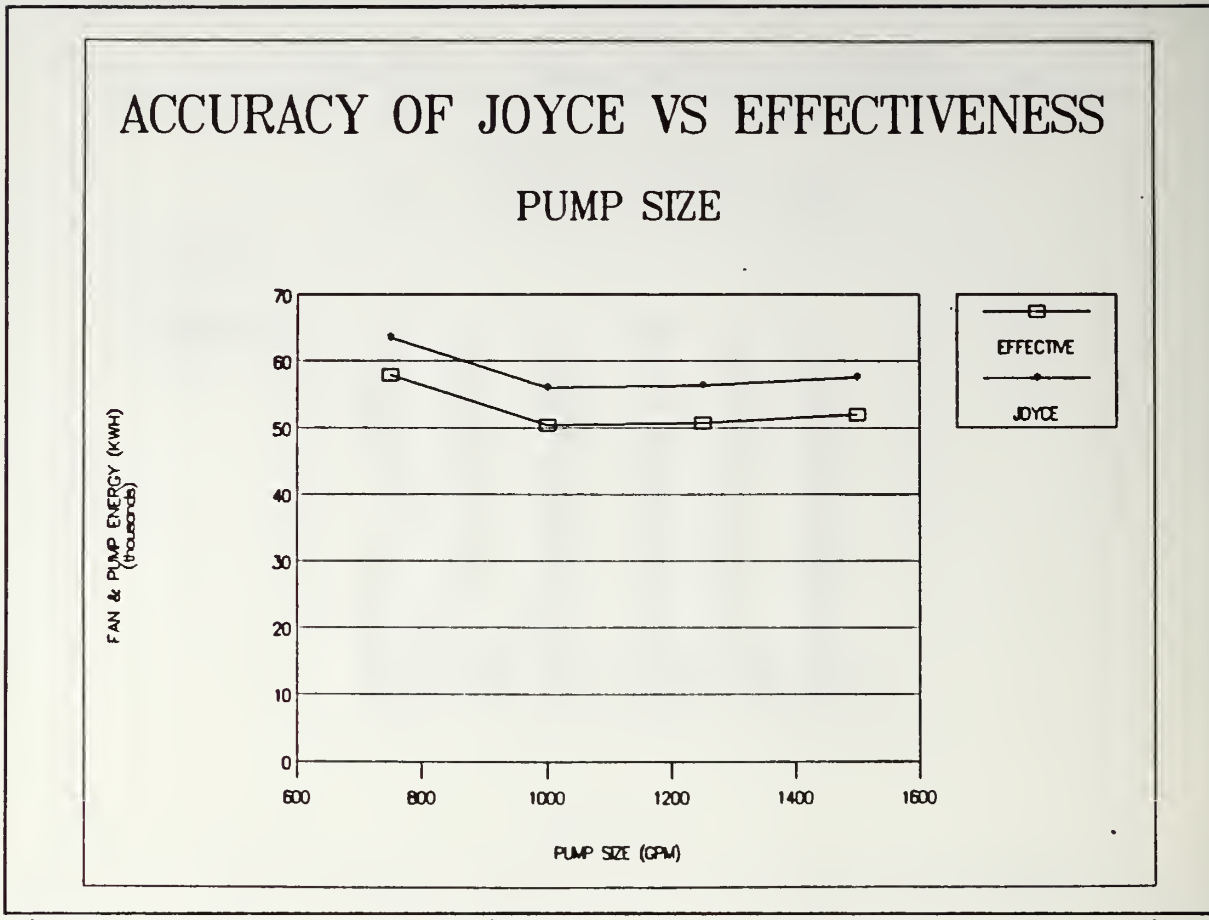

Figure 8. Plot of Effectiveness versus Joyce Data for Various Pump Sizes.

In order to improve the accuracy of the effectiveness method, crossflow correction factor should be applied and the water loss from the cooling tower should be included. The affect on computer run time, however, will be adverse as several other iteration loops would have to be utilized. Another improvement could be using a more accurate curve fit for the saturation specific heat C_s. This will also take additional computational time and would result in only a minimal improvement in accuracy.

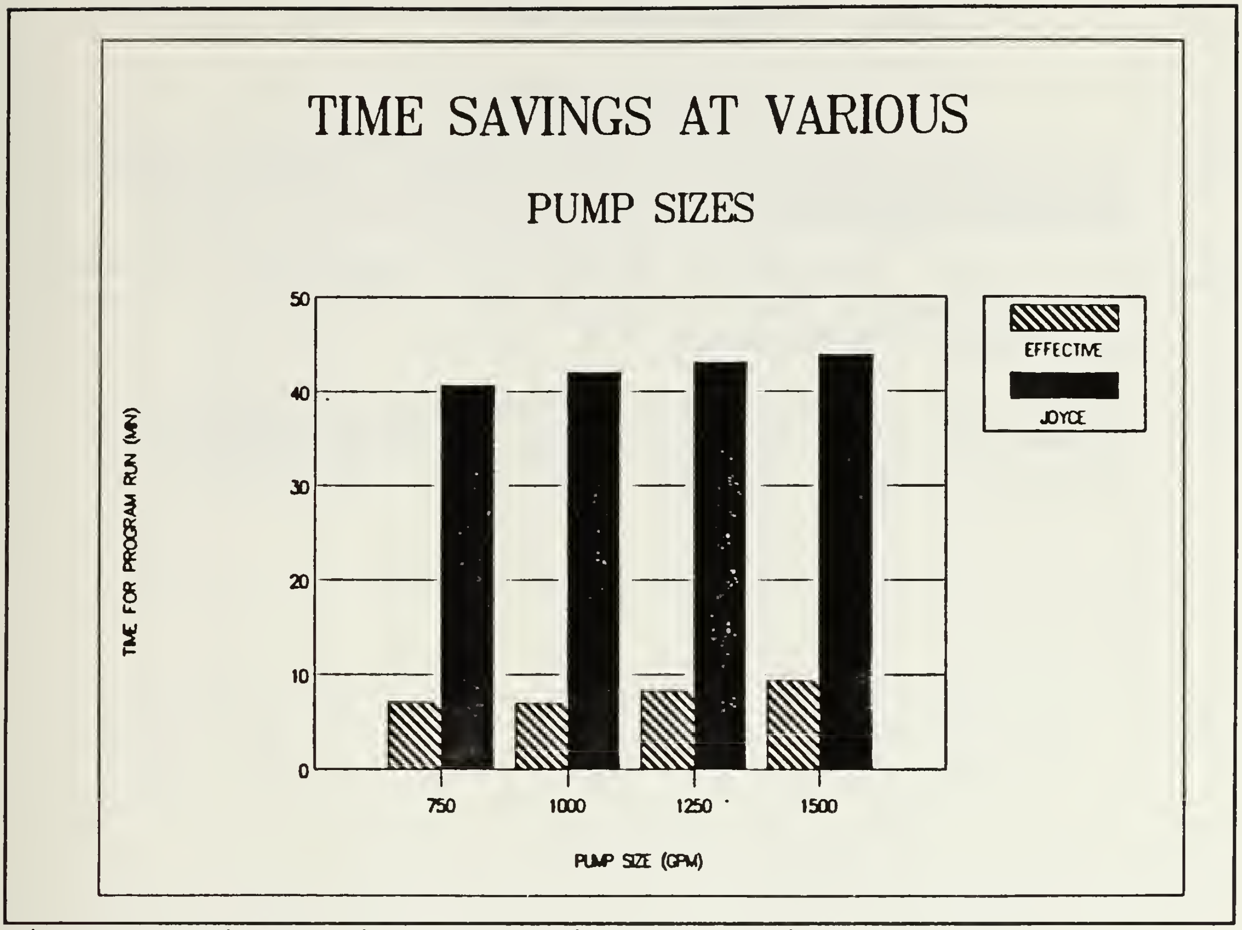

Figure 9. Time Savings at Various Pump Sizes.

The results of this project are very encouraging. For a general trend and a first time run through finding the optimum design this revised effectiveness model fits the bill. The reduction in computational time will allow an engineer flexibility in investigating various systems reaching an optimum design in a shorter time frame.

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Joyce, C. T. 1990. "Optimized Design of a Commercial Building Chiller/Cooling Tower System." Master's Thesis. Georgia Institute of Technology.

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APPENDIX A

EFFECTIVENESS COMPUTER PROGRAM

EFFECTIVENESS PROGRAM MODEL

```
'
'                           15 OCT 91
' THIS PROGRAM CALCULATES THE ANNUAL ENERGY COST, AND THE
'  CAPITAL CONSTRUCTION COST OF THE CONDENSER SIDE OF A CENTRIFUGAL
'  CHILLER PLANT.  VARIES THE CONDENSER GPM TO MAINTAIN OPT GPM FOR
'  A PARTICULAR TEMP. BIN ASSUMING 1071 GPM MAX.  USED TO COMPARE
'   FIXED SPEED DESIGN WITH VARIABLE SPEED.
'
'           INPUT PARAMETERS:
'
'                1) THE CITY (ATLANTA=1, L.A.=2, N.Y.=3)
'                2) THE COOLING TOWER NO. CORRESPONDING TO ONE OF
'                     THE COOLING TOWERS IN THE DOCUMENTATION.
'                3) THE CONDENSER WATER PIPE SIZE IN INCHES.
'                4) THE COOLING TOWER CFM.
'                5) THE NO. OF CONDENSER PASSES IN THE CHILLER.
'                6) THE MAXIMUM FLOWRATE (GPM) FOR VARIABLE SPEED
'                     PUMP.
'
'  **** THIS PROGRAM IS A MODIFICATION OF THE PROGRAM ANUALFIX
'         WRITTEN BY ERIC WEBER IN CONJUNCTION WITH HIS MASTERS
'        THESIS ENTITLED "MODELING AND GENERALIZED OPTIMIZATION OF
'         COMMERCIAL BUILDING CHILLER/COOLING TOWER SYSTEMS"
'
'__UPDATES_____________________________________________________
'     LAST UPDATE TO ANUALFIX BY EDW ON  23 OCT 1988
'     MOD TO PREVENT RECALC OF PUMP HP BY CTJ ON 3 SEPT 89
'     MOD TO PREVENT RECALC OF FAN HP BY CTJ ON 5 SEPT 89
'    MOD TO TWR CALC. FOR COOLING WITH FAN OFF BY CTJ ON 15 SEP 89
'     MOD1 TO BISECTION USE OLD CW TEMP FOR BRACKETS BY CTJ ON 29
'      SEP 89
'     MOD2 TO BISECTION TO CHECK SIGNS ON BRACKETS BY CTJ ON 30
'      SEP 89
'     MOD3 TO BISECTION WARN IF SIGNS ARE SAME BY CTJ ON 1 OCT 89
'    MOD:  STD WTHR DATA NOT COMPR. WTHR DATA BY CTJ ON 15 OCT 89
'     MOD TO ADD WTHR DATA FOR N.Y. AND L.A. BY CTJ ON  20 OCT 89
'    MOD TO ADD ENERGY BILL CALC. FOR 3 CITIES BY CTJ ON 23 OCT 89
'     MOD TO ADD CAPITAL COST FOR 3 CITIES BY CTJ ON 25 NOCT 89
'    MOD TO USE BRENT METHOD VICE OF BISECTION BY CTJ ON 27 OCT 89
'     MOD TO ASSIGN TC1 70 IF PREVIOUS HIGHER TDB ASSIGNED TC1 TO
'      70, AND CHECK FOR INCREASE IN DELTATCOND BY CTJ ON 29 OCT 89
'     MOD TO ADD VARIABLE SPEED PUMP BY CTJ ON 29 OCT 89
'      UPDATE TO INCLUDE THE EFFECTIVENESS MODEL TO CALCULATE THE
'       OUTPUT TEMP OF THE COOLING TOWER ON 15 OCT 91 BY JDR
'
DECLARE SUB EFFECTIVE (NTU!, TWIN!, MDOTW!, MDOTA!, TWB!, TDB!,
EXPTWO!, TWOUT!)
```

```
DECLARE SUB BRENT (TWIN1!, TWIN2!, DIFF1!, DIFF2!, TWOUT1!,
TWOUT2!, NTU!, fda!, MDOTW!, MDOTA!, TDB!, TWB!, DELTATCOND1!,
CTR2%, TC1!, TC2!, CITY!)
DECLARE SUB SYSCOST (PMPHP!, FANHP!, TWRCOST!, diameter!, CITY!,
CAPCST!)
DECLARE SUB ENRGYCST (KWPK!(), KWHTOT!(), BILLDEM!(), BILL!(),
YRBILL!, PMPKWH!(), FANKWH!(), CMPKWH!(), CITY!)
DECLARE SUB Hairm (T2!, T1!, W2!, OMEGMIXTURE!, HAIRMIX!)
DECLARE SUB Hairs (TF!, WS!, HSAT!)
DECLARE SUB FLOW (GPM!, CFM!, TDB!, MDOTW!, MDOTA!)
DIM HRSDAT(20), KWPK(20), KWHTOT(20), BILLDEM(20), BILL(20),
TWBR(20), TDBR(20), PMPKWH(20), FANKWH(20), CMPKWH(20)
'
'****************************
'   USER INPUT
'****************************
'
INPUT "INPUT CITY NUMBER   (1-3)    ", CITY
INPUT "INPUT TOWER NUMBER  (1-19)   ", i
INPUT "INPUT DESIRED CONDENSER WATER PIPE SIZE IN INCHES    ",
diameter
INPUT "INPUT DESIRED TOWER CFM   ", CFM
INPUT "INPUT NUMBER OF CONDENSER PASSES  ", PASSES
INPUT "INPUT THE MAXIMUM GPM FOR A VARIABLE SPEED PUMP   ", MAXGPM
'*****************************************
'STORE THE START TIME FOR THE ITERATIONS
'*****************************************
'
STARTIME$ = TIME$

'**********************************************************
' GET THE TOWER CONSTANT AND THE EXPONENT FROM DATA FILE
'**********************************************************
'

KWHSUM = 0!
TWR = i
OPEN "b:tower.dat" FOR INPUT AS #1
DO WHILE i > 0
   INPUT #1, TNUM, EXPONENT, CONSTANT, GPML, GPMH, XXX, FHPCA,
FHPCB, TWRCST
   i = i - 1!
LOOP
CLOSE #1
'
'*******************************************************
' THIS SECTION SETS UP THE DRY BULB TEMPERATURE BINS
'*******************************************************
```

```
FOR k = 1 TO 10
    TDBR(k) = 102 - ((k - 1) * 5)
NEXT k
'
'*****************************************************************
' THIS SECTION GETS THE WEATHER DATA FOR THE DRY BULB TEMP. BINS '
' FOR EACH MONTH -- JAN(i=1) thru Dec(i=12)
'*****************************************************************
'
FOR i = 1 TO 12
'
'*********************************
' INITIALIZE MONTHLY KWH AND PEAKKW
'*********************************
  KWHTOT(i) = 0!              'MONTHLY KWH
  KWPK(i) = 0!               'MAX MONTHLY KW FOR AT LEAST 15% OF HRS
                              ' IN MONTH
  PMPKWH(i) = 0!
  FANKWH(i) = 0!
  CMPKWH(i) = 0!
  CWSTEMPCHK = 0              'CHECK VALUE TO INSURE CWS TEMP DOESNT
                              ' RISE WITH DECREASING TDB, AND LOAD
  CTR% = 0                    'TRACKS # OF TEMP BINS WITH NON-0 TWB
                              ' PER MONTH
  HRSMNTH = 0!
  SELECT CASE CITY
     CASE 1
     OPEN "b:atlwth.dat" FOR INPUT AS #3
     CASE 2
     OPEN "b:lawth.dat" FOR INPUT AS #3
     CASE 3
     OPEN "b:nywth.dat" FOR INPUT AS #3
   END SELECT
   k = i
   DO WHILE k > 0!
     FOR m = 1 TO 10
      INPUT #3, HRSDAT(m), HOURSSUM, TWBR(m)
     NEXT m
     k = k - 1
   LOOP
   CLOSE #3
'
'*****************************
'SELECT THE WEATHER DATA BIN
'*****************************
'
  FOR j = 1 TO 10
   TWB = TWBR(j)                    'WET BULB TEMP
   EXPTWO = TWB                    'EXPECTED TEMP WATER FROM TOWER
                                    ' FOR EFF MODEL
```

```
    TDB = TDBR(j)                        'DRY BULB TEMP
    HOURS = HRSDAT(j)                   'MONTHLY HOURS AT TDB & TWB FROM
                                         ' 6AM TO 6PM
    IF TWB = 0 THEN GOTO GETNEXTWEATHER
    CTR% = CTR% + 1
    CTR1% = 0                             'TRACKS # OF ITTERATIONS THRU
                                           ' RESTARTA
    CTR2% = 0                             'TRACKS # OF ITTERATIONS THRU
                                           ' BRENT MTHD
    CTR3% = 0                             'TRACKS # OF ITTERATIONS THRU
                                           ' TRYAGAIN
    CTR4% = 0                             'TRACKS # OF ITTERATIONS THRU
                                           ' CYCLEFAN
'
'***************************************
'CALCULATION OF THE EVAPORATING TEMP.
'***************************************
'
   EVAPGPM = 1200                       'FLOWRATE THRU EVAPORATOR
   TE2 = 44                             'FIXED CHILLED WATER SUPPLY
                                        ' TEMP.
'
'*******************************
' EVAP LOAD ALGORITHM
'*******************************
'
   GPM = -1242 + (93.90529 * TDB) - (1.45875 * TDB ^ 2) + (.007462
* TDB ^ 3)
   IF GPM <= 775 THEN GPM = 750
   tons = -531.578 + 10.526 * TDB
   IF tons > 500 THEN
    tons = 500
   END IF
   IF tons < 100 THEN
    tons = 100
   END IF
   QDOTEVAP = tons * 12000
   DELTATEVAP = QDOTEVAP / (EVAPGPM * 499.27)
   UAEVAP  =  1000  *  (134.11603#  +  1284.3418#  *  (tons  /  500)  -
640.54974# * ((tons / 500) ^ 2))
   LMTDevap = QDOTEVAP / UAEVAP
   TE = (-TE2 - DELTATEVAP + TE2 * EXP(DELTATEVAP / LMTDevap)) /
(EXP(DELTATEVAP / LMTDevap) - 1!)
'
'***********************************
' ESTIMATE OF THE KW FOR COMPRESSOR
'***********************************
'
   KW = 30 + .61 * (tons)
```

```
  TWIN1 = 50.5
  TWIN2 = 110
'
'*****************************************************
'CALCULATE THE HEAT BURDEN FOR THE CHILLER CONDENSER
'*****************************************************
'
RESTARTA:
  QDOTCOND = QDOTEVAP + (KW * 3413)
  DELTATCOND1 = QDOTCOND / (GPM * 499.27)
  CALL FLOW(GPM, CFM, TDB, MDOTW, MDOTA)
  fda = MDOTW * CONSTANT * ((MDOTW / MDOTA) ^ EXPONENT)
  NTU = CONSTANT * ((MDOTW / MDOTA) ^ (EXPONENT + 1))
'
'******************************
' BRACKETING FOR BRENT METHOD
'******************************
'
  CALL EFFECTIVE(NTU, TWIN1, MDOTW, MDOTA, TWB, TDB, EXPTWO,
TWOUT1)
  DELTA1 = TWIN1 - TWOUT1
  DIFF1 = DELTATCOND1 - DELTA1
  CALL EFFECTIVE(NTU, TWIN2, MDOTW, MDOTA, TWB, TDB, EXPTWO,
TWOUT2)
  DELTA2 = TWIN2 - TWOUT2
  DIFF2 = DELTATCOND1 - DELTA2
  IF SGN(DIFF1) = SGN(DIFF2) THEN
    TWIN1 = TWIN1 - 5
    TWIN2 = TWIN2 + 5
    SELECT CASE CITY
     CASE 1
     OPEN "B:ATLEFF.DAT" FOR APPEND AS #4
     CASE 2
     OPEN "B:LAEFF.DAT" FOR APPEND AS #4
     CASE 3
     OPEN "B:NYEFF.DAT" FOR APPEND AS #4
    END SELECT
    PRINT #4, "ROOT NOT BRACKETED FOR BRENT. PROG ASSIGNING NEW
BRACKETS"
    PRINT #4, "MONTH= "; i, "BIN ="; TDB
    CLOSE #4
    PRINT "ROOT NOT BRACKETED FOR BRENT. PROG ASSIGNING NEW
BRACKETS"
    PRINT "MONTH= "; i, "BIN ="; TDB
    GOTO RESTARTA:
  END IF
  CTR1% = CTR1% + 1
  CALL BRENT(TWIN1, TWIN2, DIFF1, DIFF2, TWOUT1, TWOUT2, NTU, fda,
MDOTW, MDOTA, TDB, TWB, DELTATCOND1, CTR2%, TC1, TC2, CITY)
  DELTA3 = TWIN2 - TWOUT2
```

```
'
'*************************************************
' DETERMINATION OF CONDENSER PERFORMANCE (UA,Tc)
'*************************************************
'
  GPMCOND = GPM
  UAcond = 608.5483400000001# + 130.64856# * (tons / 500) -
192.20566# * ((tons / 500) ^ 2)
  UAcond = UAcond + 1203.80505# * (GPM / (PASSES * 1500)) -
557.4549# * ((GPM / (PASSES * 1500)) ^ 2)
  UAcond = UAcond * 1000
  LMTDCOND = QDOTCOND / UAcond
  TC = (TC1 - (TC1 + (TC2 - TC1)) * EXP((TC2 - TC1) / LMTDCOND)) /
(1! - EXP((TC2 - TC1) / LMTDCOND))
'
'*************************************************************
'DETERMINE MODEL KW USING THE CARNOT KW/TON AND TWO EFFICIENCIES
'*************************************************************
'
  KWCARNOT = (((TC + 460) / (TE + 460)) - 1!) * 3.517
  NfTON = 4.5869 * (tons / 500) - 8.16536 * ((tons / 500) ^ 2) +
6.65014 * ((tons / 500) ^ 3) - 2.07167 * ((tons / 500) ^ 4)
  NfISENT = .516061 + .31889 * ((KWCARNOT - .3) / .2) - .14911# *
(((KWCARNOT - .3) / .2) ^ 2)
  KWTONMODEL = KWCARNOT / (NfISENT * NfTON)
  KWTONGUESS = KW / tons
'
'**********************************************
' COMPARE MODEL KW/TON TO THE GUESSED KW/TON
'**********************************************
  IF ABS(KWTONMODEL - KWTONGUESS) > .0001 THEN
    KW = KWTONMODEL * tons
    GOTO RESTARTA
  END IF
  TC1A = TC1
  TC2A = TC2
'
'**************************************************************
' IF THE ENTERING COND. WATER TEMP. IS BELOW 80 THEN FIX IT AT 80
' AND CYCLE THE COOLING TOWER FAN.
'**************************************************************
'
 IF TC1 < 80 THEN
     GOTO CYCLEFAN
 END IF
  IF CTR% > 1 THEN
     GOTO CALCTOTALKW
  END IF
  FANHP = EXP(FHPCA + ((LOG(CFM) - 10.5) / 2!) * FHPCB)
  FanKW = ((FANHP * .7457) / .85)
  GOTO CALCTOTALKW
```

```
'
'*****************************************************************
'
'
'  THIS SECTION WILL HOLD CONDENSER WATER INPUT TEMPERATURE TO
'  80 F AND CYCLE THE TOWER FAN USING THE TOWER TEMPERATURE DROP
'  VERSUS THE CONDENSER TEMPERATURE DROP
'
'*****************************************************************
'
CYCLEFAN:
TRYAGAIN:
  CTR3% = CTR3% + 1
  QDOTCOND = QDOTEVAP + (KW * 3413)
  DELTATCOND = QDOTCOND / (GPM * 499.27)
  CALL FLOW(GPM, CFM, TDB, MDOTW, MDOTA)
  fda = MDOTW * CONSTANT * ((MDOTW / MDOTA) ^ EXPONENT)
  NTU = CONSTANT * ((MDOTW / MDOTA) ^ (EXPONENT + 1))
  TC1 = 80
  TC2 = TC1 + DELTATCOND
  CALL EFFECTIVE(NTU, TC2, MDOTW, MDOTA, TWB, TDB, EXPTWO, TWOUT1)
  DELTATTOWER = TC2 - TWOUT1
  UAcond  =  608.5483400000001#  +  130.64856#  *  (tons  /  500)  -
192.20566# * ((tons / 500) ^ 2)
  UAcond  =  UAcond  +  1203.80505#  *  (GPM  /  (PASSES  *  1500))  -
557.4549# * ((GPM / (PASSES * 1500)) ^ 2)
  UAcond = UAcond * 1000
  LMTDCOND = QDOTCOND / UAcond
  TC = (TC1 - (TC1 + (TC2 - TC1)) * EXP((TC2 - TC1) / LMTDCOND)) /
(1! - EXP((TC2 - TC1) / LMTDCOND))
  KWCARNOT = (((TC + 460) / (TE + 460)) - 1!) * 3.517
  NfTON = 4.5869 * (tons / 500) - 8.16536 * ((tons / 500) ^ 2) +
6.65014 * ((tons / 500) ^ 3) - 2.07167 * ((tons / 500) ^ 4)
  NfISENT = .516061 + .31889 * ((KWCARNOT - .3) / .2) - .14911# *
(((KWCARNOT - .3) / .2) ^ 2)
  KWTONMODEL = KWCARNOT / (NfISENT * NfTON)
  KWTONGUESS = KW / tons
  IF ABS(KWTONMODEL - KWTONGUESS) > .0001 THEN
    KW = KWTONMODEL * tons
    GOTO TRYAGAIN
  END IF
  FANHP = EXP(FHPCA + ((LOG(CFM) - 10.5) / 2!) * FHPCB)
  TOWERDUTY = (DELTATCOND - (.1 * DELTATTOWER)) / (DELTATTOWER *
.9)
  FanKW = ((FANHP * .7457) / .85) * TOWERDUTY
  CTR4% = CTR4% + 1
'
'*****************************************************************
'CALCULATION OF THE POWER REQUIRED BY THE CONDENSER WATER PUMP
'*****************************************************************
'
```

```
CALCTOTALKW:
  PipeD = diameter / 12
  Condenservelocity = (GPM * .002228) * (PASSES / 1.15241)
  Pipevelocity = (GPM * .002228) / ((3.1416 * (PipeD ^ 2)) / 4)
  REd = (Pipevelocity * PipeD) / 8.64E-06
  IF REd < 2300 THEN
    pipefrict = 64 / REd
  ELSE
' ********************************************
'  FROM EQU. 6.64a IN FLUID MECHANICS BY  WHITE
' ********************************************
    AA = (6.9 / REd) + ((.00015 / (PipeD * 3.7)) ^ 1.11)
    BB = LOG(AA) / LOG(10!)
    pipefrict = (1! / (-1.8 * BB)) ^ 2
  END IF
  PHtower = 11
  SELECT CASE PASSES
    CASE 1
      PHcond = EXP(-13.95945 + 20.21629 * (LOG(GPM) / 10))
    CASE 2
      PHcond = EXP(-10.96759 + 19.02989 * (LOG(GPM) / 10))
    CASE 3
      PHcond = EXP(-8.96627 + 17.76877 * (LOG(GPM) / 10))
    CASE 4
      PHcond = EXP(-8.76329 + 18.62906 * (LOG(GPM) / 10!))
  END SELECT
  PipeL = 200
  PipefL = 450 * PipeD
  PipestrainL = 250 * PipeD
  Ltotal = PipeL + PipefL + PipestrainL
  PHpipe = ((Pipevelocity ^ 2) / 64.4) * ((pipefrict * Ltotal) /
PipeD)
  PHTOTAL = PHcond + PHtower + PHpipe
  PERGPM = (GPM / MAXGPM) * 100
  PMPEFF = 10.57993 + (2.436639 * PERGPM) - (.01966 * (PERGPM ^ 2))
  VFDEFF = 4.983855 + (1.846339 * PERGPM) - (.01029 * (PERGPM ^ 2))
  PMPHP = (GPM * PHTOTAL) / (3960 * PMPEFF / 100)
  PumpKW = (PMPHP * .7457) / (VFDEFF / 100)
'
'*******************************************************
' CALCULATION OF THE TOTAL POWER REQUIRED BY THE SYSTEM
'*******************************************************
'
  TOTALKW = PumpKW + FanKW + KW      'TOTAL SYSTEM KW
  KWHBIN = TOTALKW * HOURS           'ENERGY CONSUMPTION OF BIN
  KWHTOT(i) = KWHTOT(i) + KWHBIN     'ENERGY CONSUMPTION OF MONTH
  KWHSUM = KWHSUM + KWHBIN           'ENERGY CONSUMPTION OVER YEAR
  PKHOURS = .15 * HOURSSUM
  IF (HOURS >= PKHOURS) AND (TOTALKW > KWPK(i)) THEN KWPK(i) =
TOTALKW
```

```
  HRSMNTH = HRSMNTH + HOURS
  PMPKWH(i) = PMPKWH(i) + (PumpKW * HOURS)
  FANKWH(i) = FANKWH(i) + (FanKW * HOURS)
  CMPKWH(i) = CMPKWH(i) + (KW * HOURS)
'
'************************************
'STORE THE END TIME FOR ITERATIONS
'************************************
'
   ENDTIME$ = TIME$
'
'*******************************************************************
' PRINTING OF THE RESULTS
'*******************************************************************
'
 SELECT CASE CITY
  CASE 1
  OPEN "B:ATLEFF.DAT" FOR APPEND AS #4
  CASE 2
  OPEN "B:LAEFF.DAT" FOR APPEND AS #4
  CASE 3
  OPEN "B:NYEFF.DAT" FOR APPEND AS #4
 END SELECT
 PRINT #4, "TIME START = "; STARTIME$; "TIME END = ", ENDTIME$
 PRINT #4, "ctr1="; CTR1%, "ctr2 = "; CTR2%, " ctr3 = "; CTR3%; ""
 PRINT #4, "I="; i, "J="; j
 PRINT #4, "TDB(DEG F)      TWB(DEG F)   HOURS           TOWER "
 PRINT #4, ; TDB, TWB, HOURS, TWR
 PRINT #4, "GPM              %GPM          CFM             TONS"
 PRINT #4, ; GPM, PERGPM, CFM, tons
 IF TC1 > 80 THEN
 PRINT #4, "CWS(DEG F)     CWR(DEG F)   DELTATCOND    DELTATTOWER"
 PRINT #4, ; TC1A, TC2A, DELTATCOND1, DELTA3
 ELSE
 PRINT #4, "CWS(DEG F)     CWR(DEG F)    DELTATCOND    DELTATTOWER
  TOWERDUTY"
 PRINT #4, ; TC1, TC2, DELTATCOND, DELTATTOWER, TOWERDUTY
 END IF
 PRINT #4, "PIPE D(FT)   Pipevelocity(FT/SEC)  REd            pipe
frict       "
 PRINT #4, ; PipeD, Pipevelocity, REd, pipefrict
 PRINT #4, "pipeL total    PHpipe          PHcond         PHtower
     PHtotal(FT Water)"
 PRINT #4, ; Ltotal, PHpipe, PHcond, PHtower, PHTOTAL
 PRINT #4, "PASSES         Condenservelocity"
 PRINT #4, ; PASSES, Condenservelocity
 '
 PRINT #4, "UACOND         LMTDCOND       NfISENT        NFTON
  COND.TEMP"
 PRINT #4, ; UAcond, LMTDCOND, NfISENT, NfTON, TC
 PRINT #4, "KWTONGUESS   KWTONMODEL     KWHBIN         KWHTOT"
```

```
 PRINT #4, ; KWTONGUESS, KWTONMODEL, KWHBIN, KWHTOT(i)
 PRINT #4, "HOURS        HOURSSUM"
 PRINT #4, ; HOURS, HOURSSUM
 PRINT #4, "CHILLERKW      PUMPKW        FANKW         TOTALKW  "
 PRINT #4, ; KW, PumpKW, FanKW, TOTALKW
 PRINT #4, ""
 PRINT #4, ""
 PRINT #4, ""
 PRINT #4, ""
 CLOSE #4
OVER:
GETNEXTWEATHER:
'*********************************
'GET THE NEXT WEATHER DATA BIN
'*********************************
NEXT j
'*********************************
'START CALC FOR THE NEXT MONTH
'**********************************
NEXT i
'
CALL  ENRGYCST(KWPK(),  KWHTOT(),  BILLDEM(),  BILL(),  YRBILL,
PMPKWH(), FANKWH(), CMPKWH(), CITY)
CALL SYSCOST(PMPHP, FANHP, TWRCST, diameter, CITY, CAPCST)
'
END



SUB BRENT (TWIN1, TWIN2, DIFF1, DIFF2, TWOUT1, TWOUT2, NTU, fda,
MDOTW, MDOTA, TDB, TWB, DELTATCOND1, CTR2%, TC1, TC2, CITY)
ITMAX = 50
TOL = .0001
EPS = 1 * 10 ^ -7
DIFF3 = DIFF2
TWOUT3 = TWOUT2
FOR ITER = 1 TO ITMAX
  CTR2% = CTR2% + 1
  IF (DIFF2 * DIFF3) > 0 THEN
    TWIN3 = TWIN1
    DIFF3 = DIFF1
    TWOUT3 = TWOUT1
    TWIN4 = TWIN2 - TWIN1
    TWIN5 = TWIN4
  END IF
  IF ABS(DIFF3) < ABS(DIFF2) THEN
    TWIN1 = TWIN2
    TWIN2 = TWIN3
    TWIN3 = TWIN1
    DIFF1 = DIFF2
```

```
  TWOUT1 = TWOUT2
  DIFF2 = DIFF3
  TWOUT2 = TWOUT3
  DIFF3 = DIFF1
  TWOUT3 = TWOUT1
END IF
TOL1 = (2 * EPS * ABS(TWIN2)) + (.5 * TOL)
XM = .5 * (TWIN3 - TWIN2)
IF (ABS(XM) <= TOL1) OR (DIFF2 = 0) THEN
   TC2 = TWIN2
   TC1 = TWOUT2
   EXIT SUB
END IF
IF (ABS(TWIN5) >= TOL1) AND (ABS(DIFF1) > ABS(DIFF2)) THEN
  S = DIFF2 / DIFF1
  IF TWIN1 = TWIN3 THEN
    P = 2 * XM * S
    Q = 1 - S
  ELSE
    Q = DIFF1 / DIFF3
    R = DIFF2 / DIFF3
    P = S * (2 * XM * Q * (Q - R) - (B - A) * (R - 1))
    Q = (Q - 1) * (R - 1) * (S - 1)
  END IF
  IF P > 0 THEN Q = -Q
  P = ABS(P)
  MIN1 = 3 * XM * Q - ABS(TOL1 * Q)
  MIN2 = ABS(TWIN5 * Q)
  IF MIN1 < MIN2 THEN
     MIN = MIN1
  ELSE
     MIN = MIN2
  END IF
  IF (2 * P) < MIN THEN
     TWIN5 = TWIN4
     TWIN4 = P / Q
  ELSE
     TWIN4 = XM
     TWIN5 = TWIN4
  END IF
ELSE
  TWIN4 = XM
  TWIN5 = TWIN4
END IF
TWIN1 = TWIN2
DIFF1 = DIFF2
TWOUT1 = TWOUT2
IF (ABS(TWIN4) > TOL1) THEN
  TWIN2 = TWIN2 + TWIN4
ELSE
  SELECT CASE XM
```

```
    CASE IS > 0
      SIGN = 1
    CASE 0
      SIGN = 1
    CASE IS < 0
      SIGN = -1
    END SELECT
    TOL2 = TOL1 * SIGN
    TWIN2 = TWIN2 + TOL2
  END IF
  CALL EFFECTIVE(NTU, TWIN2, MDOTW, MDOTA, TWB, TDB, TWB, TWOUT2)
  DELTA2 = TWIN2 - TWOUT2
  DIFF2 = DELTATCOND1 - DELTA2
NEXT ITER
  SELECT CASE CITY
   CASE 1
   OPEN "B:ATLEFF.DAT" FOR APPEND AS #1
   CASE 2
   OPEN "B:LAEFF.DAT" FOR APPEND AS #1
   CASE 3
   OPEN "B:NYEFF.DAT" FOR APPEND AS #1
  END SELECT
  PRINT #1, "BRENT METHOD EXCEEDED MAX ITERATIONS"
  TC2 = TWIN2
  TC1 = TWOUT2
  CLOSE #1
  PRINT "BRENT METHOD EXCEEDED MAX ITERATIONS"
  PRINT "MONTH ="; i, "BIN ="; TDB
END SUB


SUB EFFECTIVE (NTU, TWIN, MDOTW, MDOTA, TWB, TDB, EXPTWO, TW2)
DELTA3 = 10
Ttemp = EXPTWO
DO WHILE ABS(DELTA3) > .0001
'
'Calculate the inlet and outlet saturation enthalpy of the
'saturated air.
'
CALL Hairs(Ttemp, WSAT1, hswo)
CALL Hairs(TWIN, WSAT1, hswi)
'
'Calculate the saturation specific heat and the m* parameter as
'defined by Braun.
'
Cs = (hswi - hswo) / (TWIN - Ttemp)
m = MDOTA / (MDOTW * (1 / Cs))
eff = (1 - EXP(-NTU * (1 - m))) / (1 - m * EXP(-NTU * (1 - m)))
'
'Calculate the humidity ratio of the air-vapor mixture.
```

```
CALL Hairs(TWB, WSAT, H)
CALL Hairm(TWB, TDB, WSAT, OMEG1, hai)
hao = hai + eff * (hswi - hai)
Tref = 32
TW2 = ((MDOTW * (TWIN - Tref) - MDOTA * (hao - hai)) / (MDOTW * 1))
+ Tref
DELTA3 = TW2 - Ttemp
Ttemp = TW2
LOOP
END SUB



SUB  ENRGYCST  (KWPK(),  KWHTOT(),  BILLDEM(),  BILL(),  YRBILL,
PMPKWH(), FANKWH(), CMPKWH(), CITY)
  TOTKWH = 0
  FOR l = 1 TO 12
  TOTKWH = TOTKWH + KWHTOT(l)
  KWHTOT(l) = KWHTOT(l) + 360585
  KWPK(l) = KWPK(l) + 946
  NEXT l
  SELECT CASE CITY
    CASE 1
     GOTO ATLANTA
    CASE 2
     GOTO LOSANGELES
    CASE 3
    GOTO NEWYORK
  END SELECT
ATLANTA:
'*************************************************************
'       CALCULATION OF MONTHLY ENERGY COST IN ATLANTA
'            Georgia Power schedule PL_8_GS
'              General Commercial Service
'              Current as of June 1989
'
KWDEM = 5
FOR i = 6 TO 9
  KWSMDEM = .95 * KWPK(i)
  IF KWSMDEM > KWDEM THEN KWDEM = KWSMDEM
NEXT i
FOR i = 1 TO 12
  IF (i > 5) AND (i < 10) THEN GOTO ATLNOTWNTR
  KWWNTR = .6 * KWPK(i)
  IF KWWNTR > KWDEM THEN KWDEM = KWWNTR
ATLNOTWNTR:
NEXT i
FOR i = 6 TO 9
  IF KWPK(i) > KWDEM THEN
  BILLDEM(i) = KWPK(i)
  ELSE
```

```
  BILLDEM(i) = KWDEM
  END IF
NEXT i
FOR i = 1 TO 5
  BILLDEM(i) = KWDEM
NEXT i
FOR i = 10 TO 12
  BILLDEM(i) = KWDEM
NEXT i
'**********************************************************
' CALCULATION OF THE MONTHLY ENERGY BILL FOR ATLANTA
'**********************************************************
YRBILL = 0
PMPENGY = 0
FANENGY = 0
CMPENGY = 0
FOR i = 1 TO 12
BLOKHRS = KWHTOT(i) / BILLDEM(i)
  IF (BLOKHRS <= 200) THEN
  GOTO BASEI
  ELSEIF (BLOKHRS <= 400) THEN
  GOTO BASEII
  ELSEIF (BLOKHRS <= 600) THEN
  GOTO BASEIII
  ELSE
  GOTO BASEIV
  END IF
'
BASEI:
  IF KWHTOT(i) <= 3000 THEN
     COST1 = (.10185 * KWHTOT(i)) + 13.5
  ELSEIF KWHTOT(i) <= 10000 THEN
     COST1 = (.09282 * KWHTOT(i)) + 40.59
  ELSEIF KWHTOT(i) <= 200000 THEN
     COST1 = (.07918 * KWHTOT(i)) + 176.99
  ELSE
     COST1 = (.05972 * KWHTOT(i)) + 4068.99
  END IF
  GOTO ATLSUMBILL
'
BASEII:
  IF (BILLDEM(i) >= 5) AND (BILLDEM(i) <= 15) THEN
     COST1 = (18.314 * BILLDEM(i)) + (.01028 * KWHTOT(i)) + 13.5
  ELSEIF (BILLDEM(i) <= 50) THEN
     COST1 = (16.508 * BILLDEM(i)) + (.01028 * KWHTOT(i)) + 40.59
  ELSEIF (BILLDEM(i) <= 1000) THEN
     COST1 = (13.78 * BILLDEM(i)) + (.01028 * KWHTOT(i)) + 176.99
  ELSE
     COST1 = (9.888 * BILLDEM(i)) + (.01028 * KWHTOT(i)) + 4068.99
  END IF
  GOTO ATLSUMBILL
```

```
BASEIII:
  IF (BILLDEM(i) >= 5) AND (BILLDEM(i) <= 15) THEN
     COST1 = (19.938 * BILLDEM(i)) + (.00622 * KWHTOT(i)) + 13.5
  ELSEIF BILLDEM(i) <= 50 THEN
  COST1 = (18.132 * BILLDEM(i)) + (.00622 * KWHTOT(i)) + 40.59
  ELSEIF BILLDEM(i) <= 1000 THEN
     COST1 = (15.404 * BILLDEM(i)) + (.00622 * KWHTOT(i)) + 176.99
  ELSE
     COST1 = (11.512 * BILLDEM(i)) + (.00622 * KWHTOT(i)) + 4068.99
  END IF
  GOTO ATLSUMBILL
'
BASEIV:
  IF (BILLDEM(i) >= 5) AND (BILLDEM(i) <= 15) THEN
     COST1 = (20.46 * BILLDEM(i)) + (.00535 * KWHTOT(i)) + 13.5
  ELSEIF BILLDEM(i) <= 50 THEN
     COST1 = (18.654 * BILLDEM(i)) + (.00535 * KWHTOT(i)) + 40.59
  ELSEIF BILLDEM(i) <= 1000 THEN
     COST1 = (15.926 * BILLDEM(i)) + (.00535 * KWHTOT(i)) + 176.99
  ELSE
     COST1 = (12.034 * BILLDEM(i)) + (.00535 * KWHTOT(i)) + 4068.99
  END IF
'****** CALC. OF THE TOTAL BILL ********
ATLSUMBILL:
  FCADJ = .016896 * KWHTOT(i)
  TAX = .05 * (COST1 + FCADJ)
  BILL(i) = COST1 + FCADJ + TAX
'*****CHECK FOR MIN. BILL************
  CHKKW = BILLDEM(i) - 30
  IF CHKKW > 0 THEN
    MINBILL = (13.5 + (7.5 * CHKKW) + FCADJ) * 1.05
  ELSE
    MINBILL = (13.5 + FCADJ) * 1.05
  END IF
  IF MINBILL >= BILL(i) THEN BILL(i) = MINBILL
  YRBILL = YRBILL + BILL(i)
  PMPENGY = PMPENGY + PMPKWH(i)
  FANENGY = FANENGY + FANKWH(i)
  CMPENGY = CMPENGY + CMPKWH(i)
NEXT i
'
'
  FOR j = 1 TO 12
  OPEN "B:ATLEFF.DAT" FOR APPEND AS #4
  PRINT #4, "THE MAX MONTHLY KW =", KWPK(j)
  PRINT #4, "THE BILLING DEMAND =", BILLDEM(j)
  PRINT #4, "THE MONTHLY KWH    =", KWHTOT(j)
  PRINT #4, "THE MONTHLY BILL   = ", BILL(j)
  PRINT #4, ""
  PRINT #4, ""
  IF j = 12 THEN
```

```
    PRINT #4, "THE YEARLY TOTAL ($)  =", YRBILL
    PRINT #4, "THE PUMP ENERGY (KWH) =", PMPENGY
    PRINT #4, "THE FAN ENERGY (KWH)  =", FANENGY
    PRINT #4, "THE CHILLER ENERGY  (KWH) =", CMPENGY
    PRINT #4, "THE TOTALSYSTEM ENERGY (KWH) =", TOTKWH
    PRINT #4, ""
    PRINT #4, ""
   END IF
   CLOSE #4
   NEXT j
EXIT SUB
'
LOSANGELES:
'*****************************************************************
'*****************************************************************
'     CALCULATION OF MONTHLY ENERGY COSTS IN LOS ANGELES
'              Souther California Edison Schedule GS-2
'              General Commercial - Large
'              Eff. Date 1 June 1988
'              Current as of June 1989
'
'  ** IN LA THE MONTHLY DEMAND IS STRICTLY DET. BY THE CURRENT
'     MONTH'S PERFORMANCE. THEREFORE THE DEMAND COST IS AS FOLLOWS:
'*****************************************************************
YRBILL = 0
PMPENGY = 0
FANENGY = 0
CMPENGY = 0
FOR i = 1 TO 12
  BILLDEM(i) = KWPK(i)
  DEMCOST = 0
  IF (i > 5) AND (i < 10) GOTO LASUMMER
  MIN = 31.1
  DEMCOST = 2.7 * BILLDEM(i)
  IF KWHTOT(i) <= 180000 THEN
     ENGCOST = .07197 * KWHTOT(i)
  ELSEIF KWHTOT(i) > 180000 THEN
     ENGCOST = 12954.6 + ((KWHTOT(i) - 180000) * .04973)
  ELSE
  END IF
  GOTO LASUMBILL
LASUMMER:
  MIN = 31.1
  DEMCOST = 8.6 * BILLDEM(i)
  IF KWHTOT(i) <= 180000 THEN
     ENGCOST = .07833 * KWHTOT(i)
  ELSEIF KWHTOT(i) > 180000 THEN
     ENGCOST = 14099.4 + ((KWHTOT(i) - 180000) * .05247)
  ELSE
  END IF
'
```

```
LASUMBILL:
  COST1 = MIN + DEMCOST + ENGCOST
  SURCOST = .05 * COST1
  BILL(i) = COST1 + SURCOST
  YRBILL = YRBILL + BILL(i)
  PMPENGY = PMPENGY + PMPKWH(i)
  FANENGY = FANENGY + FANKWH(i)
  CMPENGY = CMPENGY + CMPKWH(i)
  NEXT i
'
  FOR j = 1 TO 12
  OPEN "B:LAEFF.DAT" FOR APPEND AS #4
  PRINT #4, "THE MAX MONTHLY KW IS =", KWPK(j)
  PRINT #4, "THE BILLING DEMAND    =", BILLDEM(j)
  PRINT #4, "THE MONTHLY KWH       =", KWHTOT(j)
  PRINT #4, "THE MONTHLY BILL      =", BILL(j)
  PRINT #4, ""
  PRINT #4, ""
  IF j = 12 THEN
   PRINT #4, "THE YEARLY TOTAL  ($)  =", YRBILL
   PRINT #4, "THE PUMP ENERGY (KWH)  =", PMPENGY
   PRINT #4, "THE FAN ENERGY (KWH)   =", FANENGY
   PRINT #4, "THE CHILLER ENERGY (KWH) =", CMPENGY
   PRINT #4, "THE TOTAL SYSTEM ENERGY (KWH) =", TOTKWH
   PRINT #4, ""
   PRINT #4, ""
  END IF
  CLOSE #4
  NEXT j
EXIT SUB
'
NEWYORK:
'*****************************************************************
'*****************************************************************
'    CALCULATION OF MONTHLY ENERGY COSTS IN NEW YORK  (CON. ED.)
'              Con Edison Rate Schedule No.9
'              General Commercial - Large
'              Eff. Date 1 Apr. 1987
'              Current as of July 1989
'  ** IN NY THE MONTHLY DEMAND IS STRICTLY DET. BY THE CURRENT
'     MONTHS PERFORMANCE. THEREFORE THE DEMAND COST IS AS FOLLOWS:
'*****************************************************************
YRBILL = 0
PMPENGY = 0
FANENGY = 0
CMPENGY = 0
FOR i = 1 TO 12
  BILLDEM(i) = KWPK(i)
  DEMCOST = 0
  IF (i > 5) AND (i < 10) GOTO NYSUMMER
  MIN = 74.18
```

```
  IF (BILLDEM(i) > 5) AND (BILLDEM(i) <= 900) THEN
    DEMCOST = 15.86 * BILLDEM(i)
  ELSEIF BILLDEM(i) > 900 THEN
    DEMCOST = 14274 + ((BILLDEM(i) - 900) * 13.68)
  ELSE
  END IF
  GOTO NYENGYCOST
NYSUMMER:
  MIN = 96.98
  IF (BILLDEM(i) > 5) AND (BILLDEM(i) <= 900) THEN
    DEMCOST = 20.36 * BILLDEM(i)
  ELSEIF BILLDEM(i) > 900 THEN
    DEMCOST = 18324 + ((BILLDEM(i) - 900) * 18.18)
  ELSE
  END IF
'************************************************************
'  CALCULATION OF THE ENERGY CHARGES
'************************************************************
NYENGYCOST:
  IF KWHTOT(i) <= 15000 THEN
    ENGCOST = .0562 * KWHTOT(i)
  ELSEIF KWHTOT(i) > 15000 THEN
    ENGCOST = 843! + ((KWHTOT(i) - 15000) * .0523)
  ELSE
  END IF
'
  COST1 = MIN + DEMCOST + ENGCOST
  MAXBILL = .3207 * KWHTOT(i)
  IF COST1 > MAXBILL THEN COST1 = MAXBILL
  MINBILL = MIN
  IF COST1 < MINBILL THEN COST1 = MINBILL
'
  FCADJ = .004414 * KWHTOT(i)
  TAX = .0825 * COST1
  BILL(i) = COST1 + FCADJ + TAX
  YRBILL = YRBILL + BILL(i)
  PMPENGY = PMPENGY + PMPKWH(i)
  FANENGY = FANENGY + FANKWH(i)
  CMPENGY = CMPENGY + CMPKWH(i)
NEXT i
'
FOR j = 1 TO 12
  OPEN "B:NYEFF.DAT" FOR APPEND AS #4
  PRINT #4, "THE MAX MONTHLY KW IS =", KWPK(j)
  PRINT #4, "THE BILLING DEMAND    =", BILLDEM(j)
  PRINT #4, "THE MONTHLY KWH       =", KWHTOT(j)
  PRINT #4, "THE MONTHLY BILL      =", BILL(j)
  PRINT #4, ""
  PRINT #4, ""
  IF j = 12 THEN
   PRINT #4, "THE YEARLY TOTAL  ($)    =", YRBILL
```

```
   PRINT #4, "THE PUMP ENERGY (KWH)    =", PMPENGY
   PRINT #4, "THE FAN ENERGY  (KWH)    =", FANENGY
   PRINT #4, "THE CHILLER ENERGY  (KWH) =", CMPENGY
   PRINT #4, "THE TOTALSYSTEM ENERGY (KWH) =", TOTKWH
   PRINT #4, ""
   PRINT #4, ""
   END IF
  CLOSE #4
  NEXT j
'
END SUB


SUB FLOW (GPM, CFM, TDB, MDOTW, MDOTA)
MDOTW = GPM * 8.32124 * 60!
MDOTA = CFM * (28.97 / (.73 * (TDB + 459.67))) * 60!
END SUB


SUB Hairm (T2, T1, W2, OMEGMIXTURE, HAIRMIX)
HWB = 1061 + .444 * T2
HDB = 1061 + .444 * T1
HFLUID = T2 - 32
OMEGMIXTURE = ((.24 * (T2 - T1)) + (W2 * (HWB - HFLUID))) / (HDB -
HFLUID)
HAIRMIX = (.24 * T1) + OMEGMIXTURE * (1061 + .444 * T1)
END SUB


SUB Hairs (TF, WS, HSAT)
TK = (TF - 32) * (5 / 9) + 273.15
LNPWS = -5800.2206# / TK + 1.3914993# - .04860239# * TK
LNPWS = LNPWS + .000041764768# * (TK ^ 2) - .000000014452093# * (TK
^ 3) + 6.5459673# * LOG(TK)
PWS = EXP(LNPWS)
WS = .62198 * (PWS / (101325 - PWS))
HSAT = .24 * TF + WS * (1061 + .444 * TF)
END SUB


SUB SYSCOST (PMPHP, FANHP, TWRCST, diameter, CITY, CAPCST)
'*****************************************************************
'    THIS SUB IS USED TO CALCULATE THE CAPITAL COST INVOLVED
'    IN THE CONDENSER SIDE EQUIPMENT INSTALLATION FOR THOSE
'    ITEMS WHICH HAVE A DIFFERENTIAL COST FOR THE SYSTEM MODS
' DETERMINE THE COST OF THE PUMP INCLUDING ELECT INSTALLATION
'******************************************************************
```

```
SELECT CASE PMPHP
     CASE 0 TO 5
     PMPCST = 2690
     VFDCST = 5183
     CASE IS <= 7.5
     PMPCST = 2740
     VFDCST = 5183
     CASE IS <= 10
     PMPCST = 3275
     VFDCST = 5183
     CASE IS <= 15
     PMPCST = 3765
     VFDCST = 6933
     CASE IS <= 20
     PMPCST = 4365
     VFDCST = 8618
     CASE IS <= 25
     PMPCST = 4440
     VFDCST = 10738
     CASE IS <= 30
     PMPCST = 5365
     VFDCST = 11938
     CASE IS <= 50
     PMPCST = 6795
     VFDCST = 13948
     CASE IS > 50
     PMPCST = 8720
     VFDCST = 18050
END SELECT
'*******************************************************************
' DETERMINE THE COST OF THE ELECT INSTALLATION FOR THE TOWER FAN
'*******************************************************************
SELECT CASE FANHP
     CASE 0 TO 5
     FANCST = 1315
     CASE IS <= 7.5
     FANCST = 1315
     CASE IS <= 10
     FANCST = 1450
     CASE IS <= 15
     FANCST = 1815
     CASE IS <= 20
     FANCST = 1965
     CASE IS <= 25
     FANCST = 1965
     CASE IS <= 30
     FANCST = 2500
     CASE IS <= 50
     FANCST = 2750
     CASE IS > 50
     FANCST = 4085
END SELECT
```

```
' ***************************************************************
'   DETERMINE THE CAPITAL COST OF THE PIPING,VALVING,FITTINGS
' ***************************************************************
SELECT CASE diameter
     CASE 5.05
     PIPECST = 19850
     CASE 6.07
     PIPECST = 23495
     CASE 8.07
     PIPECST = 33548
     CASE 10.02
     PIPECST = 52217
END SELECT
' **************************************************************
'  DETERMINE THE TOTAL CAPITAL COST
' **************************************************************
TOTCST = TWRCST + PMPCST + FANCST + PIPECST + VFDCST
OVRHD = .15 * TOTCST
SUB1 = TOTCST + OVRHD
PROF = .1 * SUB1
CAPCST = SUB1 + PROF
' **************************************************************
'  INCLUDE THE 1989 MEANS CITY COST INDEXES
' **************************************************************
SELECT CASE CITY
     CASE 1
     CTYINDX = .917
     CASE 2
     CTYINDX = 1.117
     CASE 3
     CTYINDX = 1.235
END SELECT
CAPCST = CAPCST * CTYINDX
SELECT CASE CITY
 CASE 1
 OPEN "B:ATLEFF.DAT" FOR APPEND AS #4
 CASE 2
 OPEN "B:LAEFF.DAT" FOR APPEND AS #4
 CASE 3
 OPEN "B:NYEFF.DAT" FOR APPEND AS #4
END SELECT
PRINT #4, "THE TOWER COST IS ", TWRCST
PRINT #4, "THE PUMP COST IS  ", PMPCST
PRINT #4, "THE FAN ELECT COST", FANCST
PRINT #4, "THE PIPE SYS COST ", PIPECST
PRINT #4, "THE SUBTOTAL IS   ", TOTCST
PRINT #4, "THE OVERHEAD      ", OVRHD
PRINT #4, "THE PROFIT IS     ", PROF
PRINT #4, "THE CITY INDEX IS ", CTYINDX
PRINT #4, "THE TOTAL COST IS ", CAPCST
CLOSE #4
END SUB
```

APPENDIX B

DATA GENERATED FROM WEBER MODEL COMPARISON

OUTPUT OF DELTA TEMPERATURE FOR EFFECTIVENESS AND JOYCE METHOD

DELTA EFFECTIVENESS (DEG F)	DELTA WEBER (DEG F)	DELTA WEBER PLUS 15%	DELTA WEBER MINUS 15%
1.6	1.4	1.61	1.19
6.4	5.9	6.79	5.02
6.5	5.9	6.79	5.02
6.5	5.9	6.79	5.02
7.8	7.3	8.39	6.2
9.8	8.9	10.235	7.57
11	10	11.5	8.5
11	10	11.5	8.5
11.1	10.4	11.96	8.84
12.2	11.2	12.88	9.52
14.5	13	14.95	11.05
14.6	13	14.95	11.05
14.6	13	14.95	11.05
19.9	17.8	20.47	15.13
20	18.1	20.82	15.39
20.1	17.8	20.47	15.13
20.2	17.8	20.47	15.13
26.9	23.4	26.91	19.89
26.9	23.4	26.91	19.89
26.9	23.4	26.91	19.89
27	23.6	27.14	20.06
28.6	25	28.75	21.25
28.8	25	28.75	21.25
29	25	28.75	21.25

APPENDIX C

DATA GENERATED FROM JOYCE MODEL COMPARISON

AT750.DAT PUMP SIZE 750 GPM JOYCE METHOD

```
MONTH=  12     BIN = 57
START TIME =  11:12:25   END TIME = 11:53:09  RUNTIME = 40:44
ctr1= 7       ctr2 =  92     ctr3 =  3
I= 12         J= 10
TDB(DEG F)      TWB(DEG F)    HOURS          TOWER
 57            52            24.82143       3
GPM            %GPM          CFM            TONS
 750           100           120000         100
CWS(DEG F)     CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80            84.03179      4.031794       19.60413       .1174005
PIPE D(FT)   Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667      4.787051      369371.3       1.592428E-02
pipeL total     PHpipe           PHcond           PHtower
PHtotal(FT Water)
 666.6667      5.666439      5.105591       11             21.77203
PASSES         Condenservelocity
 2             2.900009
UACOND         LMTDCOND      NfISENT        NFTON          COND.TEMP
 893100.2      1.690421      .5164742       .6406521       84.4407
KWTONGUESS    KWTONMODEL    KWHBIN         KWHTOT
 .9074575      .9074562      2526.094       6573.959
HOURS         HOURSSUM
 24.82143      57.5
CHILLERKW      PUMPKW        FANKW          TOTALKW
 90.74575      6.151319      4.87361        101.7707


THE YEARLY TOTAL ($)  =      334021.2
THE PUMP ENERGY (KWH) =      17345.86
THE FAN ENERGY (KWH)  =      46195.46
THE CHILLER ENERGY  (KWH) =  337459.7
THE TOTALSYSTEM ENERGY (KWH) =           401001
```

AT100.DAT PUMP SIZE 1000 GPM JOYCE METHOD

```
MONTH=  12      BIN = 57
START TIME =    11:55:00   END TIME = 12:37:03   RUNTIME = 42:03
ctr1= 7         ctr2 =  92     ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS           TOWER
 57              52             24.82143       3
GPM              %GPM          CFM             TONS
 750             75             120000         100
CWS(DEG F)       CWR(DEG F)    DELTATCOND      DELTATTOWER    TOWERDUTY
 80              84.03179      4.031794        19.60413       .1174005
PIPE D(FT)    Pipevelocity(FT/SEC)  REd              pipe frict
 .6666667        4.787051       369371.3       1.592428E-02
pipeL total       PHpipe             PHcond              PHtower
PHtotal(FT Water)
 666.6667        5.666439      5.105591        11             21.77203
PASSES           Condenservelocity
 2               2.900009
UACOND           LMTDCOND      NfISENT         NFTON          COND.TEMP
 893100.2        1.690421      .5164742        .6406521       84.4407
KWTONGUESS       KWTONMODEL    KWHBIN          KWHTOT
 .9074575        .9074562      2481.199        6469.957
HOURS            HOURSSUM
 24.82143        57.5
CHILLERKW        PUMPKW        FANKW           TOTALKW
 90.74575        4.342596      4.87361         99.96196


THE YEARLY TOTAL ($)   =       333374
THE PUMP ENERGY (KWH) =        9823.913
THE FAN ENERGY (KWH)   =       46195.46
THE CHILLER ENERGY  (KWH) =    337459.7
THE TOTALSYSTEM ENERGY (KWH) =                393479.1
```

AT125.DAT PUMP SIZE 1250 GPM JOYCE METHOD

```
MONTH=  12     BIN = 57
START TIME =   11:36:25    END TIME = 12:19:33  RUNTIME = 43:08
ctr1= 7        ctr2 =  92     ctr3 =  3
I= 12          J= 10
TDB(DEG F)       TWB(DEG F)    HOURS            TOWER
 57             52             24.82143       3
GPM             %GPM          CFM              TONS
 750            60             120000          100
CWS(DEG F)      CWR(DEG F)    DELTATCOND      DELTATTOWER    TOWERDUTY
 80             84.03179       4.031794       19.60413       .1174005
PIPE D(FT)    Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667       4.787051       369371.3        1.592428E-02
pipeL total      PHpipe            PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439       5.105591        11             21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND        NfISENT          NFTON         COND.TEMP
 893100.2        1.690421        .5164742        .6406521       84.4407
KWTONGUESS     KWTONMODEL      KWHBIN           KWHTOT
 .9074575        .9074562        2486.145        6481.415
HOURS          HOURSSUM
 24.82143        57.5
CHILLERKW        PUMPKW          FANKW            TOTALKW
 90.74575        4.541853        4.87361          100.1612


THE YEARLY TOTAL ($)  =      333380.8
THE PUMP ENERGY (KWH) =      10126.37
THE FAN ENERGY (KWH)  =      46195.46
THE CHILLER ENERGY  (KWH) =  337459.7
THE TOTALSYSTEM ENERGY (KWH) =             393781.5
```

AT150.DAT PUMP SIZE 1500 GPM JOYCE METHOD

```
MONTH=  12     BIN = 57
START TIME =   12:25:32   END TIME = 13:09:23  RUNTIME = 43:51
ctr1= 7        ctr2 =  92     ctr3 =  3
I= 12          J= 10
TDB(DEG F)       TWB(DEG F)    HOURS           TOWER
 57             52             24.82143      3
GPM             %GPM          CFM            TONS
 750            50             120000         100
CWS(DEG F)     CWR(DEG F)     DELTATCOND     DELTATTOWER    TOWERDUTY
 80            84.03179       4.031794       19.60413       .1174005
PIPE D(FT)    Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667      4.787051       369371.3       1.592428E-02
pipeL total     PHpipe            PHcond           PHtower
PHtotal(FT Water)
 666.6667      5.666439       5.105591       11             21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND         LMTDCOND       NfISENT         NFTON          COND.TEMP
 893100.2       1.690421       .5164742       .6406521       84.4407
KWTONGUESS    KWTONMODEL     KWHBIN          KWHTOT
 .9074575       .9074562       2501.478       6516.936
HOURS          HOURSSUM
 24.82143       57.5
CHILLERKW      PUMPKW          FANKW          TOTALKW
 90.74575       5.159607       4.87361        100.779


THE YEARLY TOTAL ($)   =      333485.1
THE PUMP ENERGY (KWH) =       11436.89
THE FAN ENERGY (KWH)   =      46195.46
THE CHILLER ENERGY  (KWH) =   337459.7
THE TOTALSYSTEM ENERGY (KWH) =               395092
```

ATEF750.DAT PUMP SIZE 750 GPM EFFECTIVENESS METHOD

```
MONTH=  12      BIN = 57
TIME START = 16:44:50    TIME END = 16:51:52  RUNTIME = 7:02
ctr1= 7         ctr2 =  92     ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)     HOURS           TOWER
 57             52             24.82143       3
GPM             %GPM           CFM             TONS
 750            100            120000          100
CWS(DEG F)      CWR(DEG F)     DELTATCOND     DELTATTOWER    TOWERDUTY
 80                 84.03179        4.031794          21.74524
9.490044E-02
PIPE D(FT)    Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667       4.787051       369371.3       1.592428E-02
pipeL total      PHpipe             PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439       5.105591       11              21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND        NfISENT         NFTON          COND.TEMP
 893100.2       1.690421       .5164742       .6406521        84.4407
KWTONGUESS     KWTONMODEL      KWHBIN          KWHTOT
 .9074576       .9074562       2502.91        6502.745
HOURS           HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW          FANKW           TOTALKW
 90.74576       6.151319       3.939574       100.8366


THE YEARLY TOTAL ($)   =      333296
THE PUMP ENERGY (KWH) =       17345.86
THE FAN ENERGY (KWH)   =      40526.96
THE CHILLER ENERGY  (KWH) =  337296.7
THE TOTALSYSTEM ENERGY (KWH) =              395169.5
```

ATEF100.DAT PUMP SIZE 1000 GPM EFFECTIVENESS METHOD

```
MONTH=  12     BIN = 57
TIME START = 17:22:58   TIME END = 17:29:55   RUNTIME = 6:57
ctr1= 7        ctr2 =  92     ctr3 =  3
I= 12          J= 10
TDB(DEG F)       TWB(DEG F)     HOURS          TOWER
 57             52             24.82143       3
GPM             %GPM           CFM            TONS
 750            75             120000         100
CWS(DEG F)      CWR(DEG F)     DELTATCOND     DELTATTOWER    TOWERDUTY
 80                 84.03179        4.031794        21.74524
9.490044E-02
PIPE D(FT)     Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667       4.787051       369371.3       1.592428E-02
pipeL total      PHpipe            PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439       5.105591       11             21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND       NfISENT        NFTON          COND.TEMP
 893100.2       1.690421       .5164742       .6406521       84.4407
KWTONGUESS     KWTONMODEL     KWHBIN         KWHTOT
 .9074576       .9074562       2458.015       6398.744
HOURS          HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW         FANKW          TOTALKW
 90.74576       4.342596       3.939574       99.02793



THE YEARLY TOTAL ($)   =      332648.8
THE PUMP ENERGY (KWH)  =      9823.913
THE FAN ENERGY (KWH)   =      40526.96
THE CHILLER ENERGY  (KWH) =  337296.7
THE TOTALSYSTEM ENERGY (KWH) =           387647.6
```

ATEF125.DAT PUMP SIZE 1250 GPM EFFECTIVENESS METHOD

```
MONTH=  12      BIN = 57
TIME START = 17:32:44   TIME END = 17:40:57   RUNTIME = 8:13
ctr1= 7         ctr2 =  92      ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS           TOWER
 57              52             24.82143        3
GPM              %GPM          CFM             TONS
 750             60             120000          100
CWS(DEG F)       CWR(DEG F)    DELTATCOND      DELTATTOWER    TOWERDUTY
 80                  84.03179        4.031794        21.74524
9.490044E-02
PIPE D(FT)    Pipevelocity(FT/SEC)  REd            pipe frict
 .6666667        4.787051        369371.3       1.592428E-02
pipeL total      PHpipe              PHcond            PHtower
PHtotal(FT Water)
 666.6667        5.666439        5.105591       11              21.77203
PASSES           Condenservelocity
 2               2.900009
UACOND           LMTDCOND        NfISENT         NFTON          COND.TEMP
 893100.2        1.690421        .5164742       .6406521        84.4407
KWTONGUESS    KWTONMODEL      KWHBIN          KWHTOT
 .9074576        .9074562        2462.961       6410.201
HOURS            HOURSSUM
 24.82143        57.5
CHILLERKW        PUMPKW          FANKW           TOTALKW
 90.74576        4.541853        3.939574       99.22719


THE YEARLY TOTAL ($)  =      332655.6
THE PUMP ENERGY (KWH) =      10126.37
THE FAN ENERGY (KWH)  =      40526.96
THE CHILLER ENERGY  (KWH) =  337296.7
THE TOTALSYSTEM ENERGY (KWH) =             387950
```

ATEF150.DAT PUMP SIZE 1500 GPM EFFECTIVENESS METHOD

```
MONTH=  12    BIN = 57
TIME START = 17:42:20   TIME END = 17:51:43   RUNTIME = 9:23
ctr1= 7       ctr2 =  92     ctr3 =  3
I= 12         J= 10
TDB(DEG F)      TWB(DEG F)    HOURS          TOWER
 57           52             24.82143      3
GPM           %GPM          CFM            TONS
 750          50             120000        100
CWS(DEG F)     CWR(DEG F)    DELTATCOND    DELTATTOWER    TOWERDUTY
 80                84.03179         4.031794         21.74524
9.490044E-02
PIPE D(FT)    Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667      4.787051      369371.3      1.592428E-02
pipeL total      PHpipe            PHcond           PHtower
PHtotal(FT Water)
 666.6667      5.666439      5.105591      11             21.77203
PASSES          Condenservelocity
 2             2.900009
UACOND          LMTDCOND        NfISENT         NFTON          COND.TEMP
 893100.2      1.690421      .5164742      .6406521      84.4407
KWTONGUESS    KWTONMODEL      KWHBIN          KWHTOT
 .9074576      .9074562      2478.294      6445.722
HOURS         HOURSSUM
 24.82143      57.5
CHILLERKW       PUMPKW          FANKW           TOTALKW
 90.74576      5.159607      3.939574      99.84494
```

```
THE YEARLY TOTAL ($)   =      332759.9
THE PUMP ENERGY (KWH) =      11436.89
THE FAN ENERGY (KWH)   =      40526.96
THE CHILLER ENERGY  (KWH) =  337296.7
THE TOTALSYSTEM ENERGY (KWH) =             389260.5
```

ATTOW2.DAT TOWER # 2 JOYCE METHOD

```
MONTH=  12      BIN = 57
START TIME =    10:02:55      END TIME = 10:43:28   RUNTIME = 40:33
ctr1= 7         ctr2 =  90     ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS            TOWER
 57             52             24.82143       2
GPM             %GPM           CFM             TONS
 750            75             120000          100
CWS(DEG F)      CWR(DEG F)     DELTATCOND      DELTATTOWER    TOWERDUTY
 80             84.03179       4.031794        19.00449       .1246106
PIPE D(FT)    Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667       4.787051       369371.3        1.592428E-02
pipeL total     PHpipe             PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439       5.105591        11             21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND       NfISENT         NFTON          COND.TEMP
 893100.2       1.690421       .5164742        .6406521       84.4407
KWTONGUESS      KWTONMODEL     KWHBIN          KWHTOT
 .9074574       .9074562       2541.575        6686.729
HOURS           HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW         FANKW           TOTALKW
 90.74574       4.342596       7.306037        102.3944


THE YEARLY TOTAL ($)   =       336101.8
THE PUMP ENERGY (KWH) =       9823.913
THE FAN ENERGY (KWH)   =       67227.36
THE CHILLER ENERGY  (KWH) =   337547.8
THE TOTALSYSTEM ENERGY (KWH) =                414599.1
```

ATTOW5.DAT TOWER # 5 JOYCE METHOD

```
MONTH=  12      BIN = 57
START TIME =    10:44:54     END TIME = 11:26:56    RUNTIME = 42:02
ctr1= 7         ctr2 =  92      ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS             TOWER
 57              52             24.82143       5
GPM              %GPM          CFM             TONS
 750             75             120000         100
CWS(DEG F)      CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80             84.03179       4.031794       19.60413       .1174005
PIPE D(FT)    Pipevelocity(FT/SEC)  REd            pipe frict
 .6666667       4.787051       369371.3       1.592428E-02
pipeL total      PHpipe            PHcond             PHtower
PHtotal(FT Water)
 666.6667       5.666439       5.105591       11             21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND       NfISENT         NFTON          COND.TEMP
 893100.2        1.690421       .5164742        .6406521       84.4407
KWTONGUESS      KWTONMODEL     KWHBIN          KWHTOT
 .9074575        .9074562       2481.199        6469.957
HOURS           HOURSSUM
 24.82143        57.5
CHILLERKW       PUMPKW          FANKW           TOTALKW
 90.74575        4.342596       4.87361         99.96196



THE YEARLY TOTAL ($)  =        333374
THE PUMP ENERGY (KWH) =        9823.913
THE FAN ENERGY (KWH)  =        46195.46
THE CHILLER ENERGY  (KWH) =    337459.7
THE TOTALSYSTEM ENERGY (KWH) =              393479.1
```

ATTOW9.DAT   TOWER # 9   JOYCE METHOD

```
MONTH=  12      BIN = 57
START TIME =    11:29:52    END TIME = 12:13:13   RUNTIME = 43:21
ctr1= 7         ctr2 =  91      ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS            TOWER
 57             52              24.82143       9
GPM             %GPM           CFM             TONS
 750            75              120000          100
CWS(DEG F)      CWR(DEG F)     DELTATCOND      DELTATTOWER    TOWERDUTY
 80             84.03179       4.031794        19.93193        .1136424
PIPE D(FT)     Pipevelocity(FT/SEC)  REd            pipe frict
 .6666667       4.787051        369371.3        1.592428E-02
pipeL total       PHpipe              PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439        5.105591        11              21.77203
PASSES            Condenservelocity
 2              2.900009
UACOND           LMTDCOND        NfISENT          NFTON          COND.TEMP
 893100.2        1.690421        .5164742         .6406521        84.4407
KWTONGUESS     KWTONMODEL      KWHBIN          KWHTOT
 .9074575        .9074562        2405.123        6187.521
HOURS           HOURSSUM
 24.82143        57.5
CHILLERKW        PUMPKW          FANKW           TOTALKW
 90.74575        4.342596        1.808699        96.89704


THE YEARLY TOTAL ($)   =      329604.7
THE PUMP ENERGY (KWH) =      9823.913
THE FAN ENERGY (KWH)   =      17438.78
THE CHILLER ENERGY  (KWH) =  337425.3
THE TOTALSYSTEM ENERGY (KWH) =              364687.9
```

ATTOW12.DAT   TOWER # 12   JOYCE METHOD

```
MONTH=  12        BIN = 57
START TIME =      12:21:59      END TIME = 13:02:36    RUNTIME = 40:37
ctr1= 7           ctr2 =  91      ctr3 =  3
I= 12             J= 10
TDB(DEG F)          TWB(DEG F)     HOURS             TOWER
 57                52              24.82143         12
GPM                %GPM           CFM               TONS
 750               75              120000           100
CWS(DEG F)        CWR(DEG F)     DELTATCOND        DELTATTOWER     TOWERDUTY
 80                84.03179       4.031794          19.7356         .1158782
PIPE D(FT)     Pipevelocity(FT/SEC)  REd                pipe frict
 .6666667          4.787051       369371.3          1.592428E-02
pipeL total        PHpipe              PHcond              PHtower
PHtotal(FT Water)
 666.6667          5.666439       5.105591          11               21.77203
PASSES            Condenservelocity
 2                 2.900009
UACOND            LMTDCOND       NfISENT           NFTON           COND.TEMP
 893100.2          1.690421       .5164742          .6406521        84.4407
KWTONGUESS        KWTONMODEL     KWHBIN            KWHTOT
 .9074575          .9074562       2397.792          6159.366
HOURS             HOURSSUM
 24.82143          57.5
CHILLERKW         PUMPKW         FANKW             TOTALKW
 90.74575          4.342596       1.513313          96.60166


THE YEARLY TOTAL ($)   =      329208.7
THE PUMP ENERGY (KWH) =      9823.913
THE FAN ENERGY (KWH)   =      14440.33
THE CHILLER ENERGY  (KWH) =  337443.6
THE TOTALSYSTEM ENERGY (KWH) =               361707.9
```

ATTOW16.DAT TOWER # 16 JOYCE METHOD

```
MONTH=  12      BIN = 57
START TIME =  13:04:09   END TIME = 13:46:03   RUNTIME = 41:54
ctr1= 7        ctr2 =  90     ctr3 =  3
I= 12          J= 10
TDB(DEG F)       TWB(DEG F)    HOURS          TOWER
 57             52            24.82143       16
GPM             %GPM          CFM            TONS
 750            75            120000         100
CWS(DEG F)      CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80             84.03179      4.031794       20.19933       .1106671
PIPE D(FT)    Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667       4.787051      369371.3       1.592428E-02
pipeL total      PHpipe           PHcond           PHtower
PHtotal(FT Water)
 666.6667       5.666439      5.105591       11             21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND      NfISENT        NFTON          COND.TEMP
 893100.2       1.690421      .5164742       .6406521       84.4407
KWTONGUESS     KWTONMODEL    KWHBIN         KWHTOT
 .9074575       .9074562      2385.629       6114.878
HOURS          HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW        FANKW          TOTALKW
 90.74575       4.342596      1.023324       96.11167



THE YEARLY TOTAL ($)  =      328628.1
THE PUMP ENERGY (KWH) =      9823.913
THE FAN ENERGY (KWH)  =      10003.45
THE CHILLER ENERGY  (KWH) =  337395.2
THE TOTALSYSTEM ENERGY (KWH) =             357222.5
```

ATTOW19.DAT TOWER # 19 JOYCE METHOD

```
MONTH=  12      BIN = 57
START TIME =    14:35:43    END TIME = 15:19:20   RUNTIME = 43:37
ctr1= 7         ctr2 =  90     ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS            TOWER
 57               52            24.82143        19
GPM               %GPM         CFM             TONS
 750              75            120000          100
CWS(DEG F)       CWR(DEG F)    DELTATCOND      DELTATTOWER    TOWERDUTY
 80               84.03179      4.031794        20.77497       .104522
PIPE D(FT)    Pipevelocity(FT/SEC)  REd               pipe frict
 .6666667         4.787051      369371.3        1.592428E-02
pipeL total      PHpipe              PHcond             PHtower
PHtotal(FT Water)
 666.6667        5.666439      5.105591        11              21.77203
PASSES           Condenservelocity
 2                2.900009
UACOND           LMTDCOND      NfISENT          NFTON         COND.TEMP
 893100.2         1.690421      .5164742        .6406521       84.4407
KWTONGUESS       KWTONMODEL    KWHBIN          KWHTOT
 .9074577         .9074562      2385.587        6115.9
HOURS            HOURSSUM
 24.82143         57.5
CHILLERKW         PUMPKW        FANKW           TOTALKW
 90.74577         4.342596      1.021625        96.10999


THE YEARLY TOTAL ($)  =      328658.3
THE PUMP ENERGY (KWH) =      9823.913
THE FAN ENERGY (KWH)  =      10252.19
THE CHILLER ENERGY  (KWH) =  337320.8
THE TOTALSYSTEM ENERGY (KWH) =             357396.9
```

ATEF2.DAT   TOWER # 2   EFFECTIVENESS METHOD

```
MONTH=  12     BIN = 57
TIME START = 15:37:19    TIME END = 15:44:00   RUNTIME = 6:41
ctr1= 7        ctr2 =  91     ctr3 =  3
I= 12          J= 10
TDB(DEG F)       TWB(DEG F)    HOURS           TOWER
 57             52             24.82143      2
GPM             %GPM          CFM             TONS
 750            75             120000         100
CWS(DEG F)      CWR(DEG F)    DELTATCOND      DELTATTOWER    TOWERDUTY
 80             84.03179      4.031794        20.96244       .1025935
PIPE D(FT)     Pipevelocity(FT/SEC)  REd             pipe frict
 .6666667       4.787051       369371.3       1.592428E-02
pipeL total      PHpipe             PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439      5.105591       11              21.77203
PASSES         Condenservelocity
 2              2.900009
UACOND         LMTDCOND        NfISENT         NFTON          COND.TEMP
 893100.2       1.690421       .5164742        .6406521       84.4407
KWTONGUESS    KWTONMODEL      KWHBIN          KWHTOT
 .9074575       .9074562       2509.533        6588.154
HOURS         HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW          FANKW           TOTALKW
 90.74575       4.342596       6.015156        101.1035


THE YEARLY TOTAL ($)   =       335101.8
THE PUMP ENERGY (KWH) =       9823.913
THE FAN ENERGY (KWH)   =       59464.87
THE CHILLER ENERGY  (KWH) =  337298.5
THE TOTALSYSTEM ENERGY (KWH) =              406587.3
```

ATEF5.DAT TOWER # 5 EFFECTIVENESS METHOD

```
MONTH=  12    BIN = 57
TIME START = 15:46:17   TIME END = 15:54:27    RUNTIME = 8:10
ctr1= 7       ctr2 =  92    ctr3 =  3
I= 12         J= 10
TDB(DEG F)      TWB(DEG F)   HOURS          TOWER
 57            52            24.82143      5
GPM            %GPM         CFM            TONS
 750           75            120000        100
CWS(DEG F)     CWR(DEG F)    DELTATCOND    DELTATTOWER    TOWERDUTY
 80                84.03179        4.031794        21.74524
9.490044E-02
PIPE D(FT)    Pipevelocity(FT/SEC)  REd         pipe frict
 .6666667      4.787051      369371.3      1.592428E-02
pipeL total     PHpipe          PHcond          PHtower
PHtotal(FT Water)
 666.6667      5.666439      5.105591      11             21.77203
PASSES          Condenservelocity
 2             2.900009
UACOND         LMTDCOND       NfISENT        NFTON          COND.TEMP
 893100.2      1.690421      .5164742      .6406521       84.4407
KWTONGUESS     KWTONMODEL     KWHBIN         KWHTOT
 .9074576      .9074562      2458.015      6398.744
HOURS          HOURSSUM
 24.82143      57.5
CHILLERKW      PUMPKW         FANKW          TOTALKW
 90.74576      4.342596      3.939574      99.02793



THE YEARLY TOTAL ($)   =      332648.8
THE PUMP ENERGY (KWH) =      9823.913
THE FAN ENERGY (KWH)   =      40526.96
THE CHILLER ENERGY  (KWH) =  337296.7
THE TOTALSYSTEM ENERGY (KWH) =              387647.6
```

ATEF9.DAT   TOWER # 9   EFFECTIVENESS METHOD

```
MONTH=  12      BIN = 57
TIME START = 15:57:15   TIME END = 16:06:35    RUNTIME = 9:20
ctr1= 7         ctr2 =  92      ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS           TOWER
 57             52              24.82143       9
GPM             %GPM           CFM             TONS
 750            75              120000          100
CWS(DEG F)      CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80                 84.03179         4.031794         22.17689
9.089065E-02
PIPE D(FT)    Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667       4.787051        369371.3        1.592428E-02
pipeL total       PHpipe             PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439        5.105591        11              21.77203
PASSES            Condenservelocity
 2              2.900009
UACOND          LMTDCOND        NfISENT         NFTON          COND.TEMP
 893100.2       1.690421        .5164742        .6406521        84.4407
KWTONGUESS    KWTONMODEL      KWHBIN          KWHTOT
 .9074577       .9074562        2396.136        6159.948
HOURS           HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW          FANKW           TOTALKW
 90.74577       4.342596        1.446589        96.53496


THE YEARLY TOTAL ($)  =       329324.2
THE PUMP ENERGY (KWH) =       9823.913
THE FAN ENERGY (KWH)  =       15236.21
THE CHILLER ENERGY  (KWH) =   337296.9
THE TOTALSYSTEM ENERGY (KWH) =              362357
```

ATEF12.DAT   TOWER # 12   EFFECTIVENESS METHOD

```
MONTH=  12      BIN = 57
TIME START = 16:28:21   TIME END = 16:35:14   RUNTIME = 6:53
ctr1= 7         ctr2 =  93      ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS             TOWER
 57              52             24.82143        12
GPM              %GPM          CFM              TONS
 750             75             120000          100
CWS(DEG F)      CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80                 84.03179        4.031794          21.91807
9.327599E-02
PIPE D(FT)    Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667        4.787051       369371.3        1.592428E-02
pipeL total       PHpipe            PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439       5.105591       11             21.77203
PASSES           Condenservelocity
 2               2.900009
UACOND          LMTDCOND        NfISENT        NFTON          COND.TEMP
 893100.2        1.690421       .5164742       .6406521        84.4407
KWTONGUESS     KWTONMODEL      KWHBIN         KWHTOT
 .9074577        .9074562       2390.465       6136.881
HOURS           HOURSSUM
 24.82143        57.5
CHILLERKW        PUMPKW         FANKW          TOTALKW
 90.74577        4.342596       1.218139       96.30651


THE YEARLY TOTAL ($)   =       328978.1
THE PUMP ENERGY (KWH) =       9823.913
THE FAN ENERGY (KWH)   =       12646.48
THE CHILLER ENERGY  (KWH) =  337296.8
THE TOTALSYSTEM ENERGY (KWH) =              359767.2
```

```
MONTH=  12     BIN = 57
TIME START = 16:36:34   TIME END = 16:44:47   RUNTIME = 8:13
ctr1= 7        ctr2 =  91     ctr3 =  3
I= 12          J= 10
TDB(DEG F)       TWB(DEG F)    HOURS           TOWER
 57             52             24.82143       16
GPM             %GPM          CFM            TONS
 750            75             120000         100
CWS(DEG F)      CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80                 84.03179        4.031794         22.53072
8.771837E-02
PIPE D(FT)    Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667      4.787051       369371.3       1.592428E-02
pipeL total      PHpipe              PHcond            PHtower
PHtotal(FT Water)
 666.6667      5.666439      5.105591      11             21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND         LMTDCOND        NfISENT        NFTON          COND.TEMP
 893100.2       1.690421       .5164742       .6406521       84.4407
KWTONGUESS     KWTONMODEL     KWHBIN         KWHTOT
 .9074577       .9074562       2380.363       6098.738
HOURS          HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW         FANKW          TOTALKW
 90.74577       4.342596       .8111207       95.89949


THE YEARLY TOTAL ($)  =       328464.3
THE PUMP ENERGY (KWH) =       9823.913
THE FAN ENERGY (KWH)  =       8709.041
THE CHILLER ENERGY  (KWH) =   337297.1
THE TOTALSYSTEM ENERGY (KWH) =             355830.1
```

ATEF19.DAT TOWER # 19 EFFECTIVENESS METHOD

```
MONTH=  12      BIN = 57
TIME START = 16:46:15   TIME END = 16:55:43   RUNTIME = 9:28
ctr1= 8         ctr2 =  104    ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS          TOWER
 57             52             24.82143      19
GPM             %GPM          CFM             TONS
 750            75             120000         100
CWS(DEG F)      CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80                 84.03179         4.031794         23.29736
8.117554E-02
PIPE D(FT)    Pipevelocity(FT/SEC)  REd          pipe frict
 .6666667       4.787051       369371.3       1.592428E-02
pipeL total      PHpipe           PHcond           PHtower
PHtotal(FT Water)
 666.6667       5.666439       5.105591       11             21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND       NfISENT        NFTON          COND.TEMP
 893100.2        1.690421       .5164742       .6406521       84.4407
KWTONGUESS      KWTONMODEL     KWHBIN         KWHTOT
 .9074578        .9074562       2379.924       6098.561
HOURS           HOURSSUM
 24.82143        57.5
CHILLERKW       PUMPKW         FANKW          TOTALKW
 90.74578        4.342596       .7934307       95.88181


THE YEARLY TOTAL ($)   =       328486.1
THE PUMP ENERGY (KWH) =       9823.913
THE FAN ENERGY (KWH)  =       8849.848
THE CHILLER ENERGY  (KWH) =  337296.8
THE TOTALSYSTEM ENERGY (KWH) =              355970.5
```

ATFM08.DAT CFM 80,000 JOYCE METHOD

```
MONTH=  12     BIN = 57
START TIME = 14:10:57    END TIME = 14:51:45   RUNTIME = 40:48
ctr1= 6        ctr2 =  80     ctr3 =  3
I= 12          J= 10
TDB(DEG F)       TWB(DEG F)    HOURS          TOWER
 57             52             24.82143      8
GPM             %GPM          CFM            TONS
 750            75             80000          100
CWS(DEG F)      CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80             84.03179      4.031793       14.52383       .1973316
PIPE D(FT)    Pipevelocity(FT/SEC)  REd          pipe frict
 .6666667       4.787051       369371.3       1.592428E-02
pipeL total      PHpipe            PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439       5.105591       11             21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND         LMTDCOND       NfISENT        NFTON          COND.TEMP
 893100.2       1.690421       .5164742       .6406521       84.4407
KWTONGUESS     KWTONMODEL     KWHBIN         KWHTOT
 .9074569       .9074562       2386.287       6108.143
HOURS          HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW        FANKW          TOTALKW
 90.74569       4.342596       1.049877       96.13816



THE YEARLY TOTAL ($)  =       329347.2
THE PUMP ENERGY (KWH) =       9823.913
THE FAN ENERGY (KWH)  =       7669.604
THE CHILLER ENERGY  (KWH) =   341085.2
THE TOTALSYSTEM ENERGY (KWH) =              358578.7
```

ATFM10.DAT CFM 100,000 JOYCE METHOD

```
MONTH=  12      BIN = 57
START TIME = 15:34:44    END TIME = 16:17:07   RUNTIME = 42:23
ctr1= 6         ctr2 =  80      ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS            TOWER
 57              52             24.82143       8
GPM              %GPM          CFM             TONS
 750             75             100000          100
CWS(DEG F)      CWR(DEG F)     DELTATCOND     DELTATTOWER    TOWERDUTY
 80             84.03179       4.031794       16.90012       .1539621
PIPE D(FT)    Pipevelocity(FT/SEC)  REd             pipe frict
 .6666667        4.787051       369371.3       1.592428E-02
pipeL total      PHpipe            PHcond            PHtower
PHtotal(FT Water)
 666.6667        5.666439       5.105591       11             21.77203
PASSES           Condenservelocity
 2               2.900009
UACOND          LMTDCOND       NfISENT         NFTON          COND.TEMP
 893100.2        1.690421       .5164742       .6406521       84.4407
KWTONGUESS      KWTONMODEL     KWHBIN          KWHTOT
 .9074571        .9074562       2401.928       6167.014
HOURS           HOURSSUM
 24.82143        57.5
CHILLERKW        PUMPKW         FANKW           TOTALKW
 90.74571        4.342596       1.680003       96.76831


THE YEARLY TOTAL ($)  =        329446
THE PUMP ENERGY (KWH) =        9823.913
THE FAN ENERGY (KWH)  =        13997.07
THE CHILLER ENERGY  (KWH) =    338508.3
THE TOTALSYSTEM ENERGY (KWH) =              362329.2
```

ATFM12.DAT CFM 120,000 JOYCE METHOD

```
MONTH=  12     BIN = 57
START TIME = 09:38:23    END TIME = 10:19:09   RUNTIME = 40:46
ctr1= 7        ctr2 =  91     ctr3 =  3
I= 12          J= 10
TDB(DEG F)        TWB(DEG F)    HOURS           TOWER
 57               52            24.82143       8
GPM               %GPM         CFM             TONS
 750              75            120000          100
CWS(DEG F)       CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80               84.03179      4.031794        18.92442       .1256079
PIPE D(FT)    Pipevelocity(FT/SEC)  REd             pipe frict
 .6666667         4.787051      369371.3        1.592428E-02
pipeL total       PHpipe              PHcond               PHtower
PHtotal(FT Water)
 666.6667         5.666439      5.105591        11             21.77203
PASSES           Condenservelocity
 2                2.900009
UACOND           LMTDCOND      NfISENT          NFTON          COND.TEMP
 893100.2         1.690421      .5164742         .6406521       84.4407
KWTONGUESS     KWTONMODEL     KWHBIN          KWHTOT
 .9074574         .9074562      2421.411        6244.041
HOURS            HOURSSUM
 24.82143         57.5
CHILLERKW         PUMPKW        FANKW           TOTALKW
 90.74574         4.342596      2.464895        97.55323


THE YEARLY TOTAL ($)   =      330303.3
THE PUMP ENERGY (KWH) =      9823.913
THE FAN ENERGY (KWH)   =      22643.94
THE CHILLER ENERGY  (KWH) =  337620.4
THE TOTALSYSTEM ENERGY (KWH) =              370088.2
```

ATFM14.DAT   CFM 140,000   JOYCE METHOD

```
MONTH=  12       BIN = 57
START TIME = 09:20:36    END TIME = 10:03:05   RUNTIME = 42:29
ctr1= 7          ctr2 =  90      ctr3 =  3
I= 12            J= 10
TDB(DEG F)         TWB(DEG F)    HOURS            TOWER
 57               52             24.82143        8
GPM               %GPM          CFM              TONS
 750              75             140000          100
CWS(DEG F)       CWR(DEG F)     DELTATCOND      DELTATTOWER    TOWERDUTY
 80              84.03179       4.031794        20.65385       .1057865
PIPE D(FT)    Pipevelocity(FT/SEC)  REd              pipe frict
 .6666667        4.787051       369371.3        1.592428E-02
pipeL total      PHpipe              PHcond             PHtower
PHtotal(FT Water)
 666.6667        5.666439       5.105591        11             21.77203
PASSES           Condenservelocity
 2               2.900009
UACOND           LMTDCOND       NfISENT         NFTON          COND.TEMP
 893100.2        1.690421       .5164742        .6406521       84.4407
KWTONGUESS       KWTONMODEL     KWHBIN          KWHTOT
 .9074576        .9074562       2444.862        6341.728
HOURS            HOURSSUM
 24.82143        57.5
CHILLERKW        PUMPKW         FANKW           TOTALKW
 90.74576        4.342596       3.409683        98.49804


THE YEARLY TOTAL ($)   =        331787.7
THE PUMP ENERGY (KWH) =        9823.913
THE FAN ENERGY (KWH)   =        34027.18
THE CHILLER ENERGY  (KWH) =    337324.1
THE TOTALSYSTEM ENERGY (KWH) =                 381175.2
```

ATFM16.DAT CFM 160,000 JOYCE METHOD

```
MONTH=  12      BIN = 57
START TIME = 10:04:59   END TIME = 10:48:51   RUNTIME = 43:52
ctr1= 8         ctr2 =  100    ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS            TOWER
 57              52              24.82143       8
GPM              %GPM          CFM              TONS
 750             75              160000          100
CWS(DEG F)      CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80                 84.03179        4.031794         22.13515
9.127153E-02
PIPE D(FT)    Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667       4.787051       369371.3       1.592428E-02
pipeL total      PHpipe            PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439       5.105591       11              21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND       NfISENT         NFTON          COND.TEMP
 893100.2        1.690421       .5164742        .6406521        84.4407
KWTONGUESS    KWTONMODEL      KWHBIN          KWHTOT
 .9074579        .9074562       2472.463        6462.413
HOURS          HOURSSUM
 24.82143        57.5
CHILLERKW       PUMPKW          FANKW           TOTALKW
 90.74579        4.342596       4.521638        99.61002


THE YEARLY TOTAL ($)   =      333746.1
THE PUMP ENERGY (KWH) =      9823.913
THE FAN ENERGY (KWH)  =      48544.85
THE CHILLER ENERGY  (KWH) =  337296.6
THE TOTALSYSTEM ENERGY (KWH) =              395665.4
```

ATFM18.DAT CFM 180,000 JOYCE METHOD

```
MONTH=  12      BIN = 57
START TIME = 13:28:34   END TIME = 14:09:48   RUNTIME = 41:14
ctr1= 8         ctr2 =  94      ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS            TOWER
 57             52              24.82143        8
GPM             %GPM            CFM             TONS
 750            75              180000          100
CWS(DEG F)      CWR(DEG F)      DELTATCOND      DELTATTOWER     TOWERDUTY
 80             84.03179        4.031794        23.40676        .0802768
PIPE D(FT)      Pipevelocity(FT/SEC)  REd              pipe frict
 .6666667       4.787051        369371.3        1.592428E-02
pipeL total       PHpipe              PHcond             PHtower
PHtotal(FT Water)
 666.6667       5.666439        5.105591        11              21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND        NfISENT         NFTON           COND.TEMP
 893100.2       1.690421        .5164742        .6406521        84.4407
KWTONGUESS      KWTONMODEL      KWHBIN          KWHTOT
 .9074581       .9074562        2504.454        6608.818
HOURS           HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW          FANKW           TOTALKW
 90.7458        4.342596        5.810467        100.8989


THE YEARLY TOTAL ($)   =        336225.5
THE PUMP ENERGY (KWH)  =        9823.913
THE FAN ENERGY (KWH)   =        66800.08
THE CHILLER ENERGY  (KWH) =     337297.3
THE TOTALSYSTEM ENERGY (KWH) =                  413921.3
```

AFMEF08.DAT CFM 80,000 EFFECTIVENESS METHOD

```
MONTH=  12     BIN = 57
TIME START = 14:16:25   TIME END = 14:24:02   RUNTIME = 7:37
ctr1= 6        ctr2 =  85     ctr3 =  3
I= 12          J= 10
TDB(DEG F)       TWB(DEG F)    HOURS           TOWER
 57             52            24.82143       8
GPM             %GPM          CFM             TONS
 750            75            80000           100
CWS(DEG F)      CWR(DEG F)    DELTATCOND      DELTATTOWER    TOWERDUTY
 80             84.03179      4.031794        15.58475       .1763346
PIPE D(FT)    Pipevelocity(FT/SEC)  REd            pipe frict
 .6666667       4.787051      369371.3        1.592428E-02
pipeL total      PHpipe           PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439      5.105591        11             21.77203
PASSES         Condenservelocity
 2              2.900009
UACOND         LMTDCOND       NfISENT         NFTON          COND.TEMP
 893100.2       1.690421      .5164742        .6406521       84.4407
KWTONGUESS    KWTONMODEL     KWHBIN           KWHTOT
 .907457        .9074562      2383.514        6099.48
HOURS          HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW        FANKW           TOTALKW
 90.7457        4.342596      .9381654        96.02646


THE YEARLY TOTAL ($)   =      328801.4
THE PUMP ENERGY (KWH) =      9823.913
THE FAN ENERGY (KWH)   =      7206.588
THE CHILLER ENERGY  (KWH) =  339184.5
THE TOTALSYSTEM ENERGY (KWH) =            356215
```

AFMEF10.DAT CFM 100,000 EFFECTIVENESS METHOD

```
MONTH=  12      BIN = 57
TIME START = 14:28:05   TIME END = 14:36:57   RUNTIME = 8:52
ctr1= 6         ctr2 =  81      ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS           TOWER
 57              52             24.82143       8
GPM              %GPM          CFM             TONS
 750             75             100000          100
CWS(DEG F)      CWR(DEG F)     DELTATCOND     DELTATTOWER    TOWERDUTY
 80             84.03179       4.031794       18.4128        .1321855
PIPE D(FT)    Pipevelocity(FT/SEC)  REd             pipe frict
 .6666667       4.787051       369371.3       1.592428E-02
pipeL total      PHpipe             PHcond             PHtower
PHtotal(FT Water)
 666.6667       5.666439       5.105591       11             21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND       NfISENT         NFTON         COND.TEMP
 893100.2        1.690421       .5164742       .6406521       84.4407
KWTONGUESS     KWTONMODEL     KWHBIN          KWHTOT
 .9074572       .9074562       2396.03        6148.765
HOURS          HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW         FANKW          TOTALKW
 90.74572       4.342596       1.442381       96.53069


THE YEARLY TOTAL ($)   =      329002.8
THE PUMP ENERGY (KWH) =       9823.913
THE FAN ENERGY (KWH)  =       12707.91
THE CHILLER ENERGY  (KWH) =   337642.3
THE TOTALSYSTEM ENERGY (KWH) =             360174.1
```

AFMEF12.DAT CFM 120,000 EFFECTIVENESS METHOD

```
MONTH=  12      BIN = 57
TIME START = 12:46:37   TIME END = 12:53:25   RUNTIME = 6:48
ctr1= 7         ctr2 =  92      ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS             TOWER
 57              52             24.82143        8
GPM              %GPM          CFM              TONS
 750             75             120000          100
CWS(DEG F)       CWR(DEG F)    DELTATCOND      DELTATTOWER    TOWERDUTY
 80              84.03179       4.031794        20.85859       .1036575
PIPE D(FT)   Pipevelocity(FT/SEC)  REd              pipe frict
 .6666667        4.787051       369371.3        1.592428E-02
pipeL total       PHpipe             PHcond             PHtower
PHtotal(FT Water)
 666.6667        5.666439       5.105591        11             21.77203
PASSES           Condenservelocity
 2               2.900009
UACOND           LMTDCOND       NfISENT          NFTON          COND.TEMP
 893100.2        1.690421       .5164742        .6406521        84.4407
KWTONGUESS     KWTONMODEL      KWHBIN           KWHTOT
 .9074575        .9074562       2410.719        6211.164
HOURS           HOURSSUM
 24.82143        57.5
CHILLERKW        PUMPKW         FANKW            TOTALKW
 90.74575        4.342596       2.034147        97.12249


THE YEARLY TOTAL ($)   =       329947.8
THE PUMP ENERGY (KWH) =       9823.913
THE FAN ENERGY (KWH)   =       20089.43
THE CHILLER ENERGY  (KWH) =  337312.3
THE TOTALSYSTEM ENERGY (KWH) =             367225.7
```

```
MONTH=  12      BIN = 57
TIME START = 12:54:56   TIME END = 13:03:20   RUNTIME = 8:24
ctr1= 8         ctr2 =  104    ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS           TOWER
 57             52             24.82143       8
GPM             %GPM          CFM             TONS
 750            75             140000         100
CWS(DEG F)      CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80                  84.03179        4.031794         22.95394
8.405238E-02
PIPE D(FT)    Pipevelocity(FT/SEC)  REd          pipe frict
 .6666667       4.787051       369371.3       1.592428E-02
pipeL total      PHpipe            PHcond            PHtower
PHtotal(FT Water)
 666.6667       5.666439       5.105591       11             21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND       NfISENT        NFTON          COND.TEMP
 893100.2       1.690421       .5164742       .6406521       84.4407
KWTONGUESS      KWTONMODEL     KWHBIN         KWHTOT
 .9074579       .9074562       2427.475       6288.67
HOURS           HOURSSUM
 24.82143       57.5
CHILLERKW       PUMPKW         FANKW          TOTALKW
 90.74579       4.342596       2.709155       97.79754


THE YEARLY TOTAL ($)   =       331261.7
THE PUMP ENERGY (KWH) =        9823.913
THE FAN ENERGY (KWH)  =        29775.94
THE CHILLER ENERGY  (KWH) =    337297
THE TOTALSYSTEM ENERGY (KWH) =               376896.8
```

AFMEF16.DAT   CFM 160,000   EFFECTIVENESS METHOD

```
MONTH=  12      BIN = 57
TIME START = 11:06:16   TIME END = 11:13:18   RUNTIME = 7:02
ctr1= 8         ctr2 =  105    ctr3 =  3
I= 12           J= 10
TDB(DEG F)        TWB(DEG F)    HOURS           TOWER
 57              52            24.82143       8
GPM              %GPM         CFM             TONS
 750             75            160000         100
CWS(DEG F)      CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80              84.03179      4.031794       24.73064       .0700314
PIPE D(FT)     Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667        4.787051      369371.3       1.592428E-02
pipeL total      PHpipe           PHcond            PHtower
PHtotal(FT Water)
 666.6667        5.666439      5.105591       11             21.77203
PASSES          Condenservelocity
 2               2.900009
UACOND          LMTDCOND       NfISENT          NFTON          COND.TEMP
 893100.2        1.690421      .5164742        .6406521       84.4407
KWTONGUESS     KWTONMODEL     KWHBIN         KWHTOT
 .9074581        .9074562      2446.345       6383.272
HOURS          HOURSSUM
 24.82143        57.5
CHILLERKW        PUMPKW         FANKW          TOTALKW
 90.7458         4.342596      3.469392       98.55779


THE YEARLY TOTAL ($)   =       332982.5
THE PUMP ENERGY (KWH) =       9823.913
THE FAN ENERGY (KWH)   =       42322.18
THE CHILLER ENERGY  (KWH) =  337297.3
THE TOTALSYSTEM ENERGY (KWH) =              389443.3
```

AFMEF18.DAT CFM 180,000 EFFECTIVENESS METHOD

```
MONTH=  12     BIN = 57
TIME START = 12:18:54   TIME END = 12:27:39   RUNTIME = 8:45
ctr1= 9        ctr2 =  116    ctr3 =  3
I= 12          J= 10
TDB(DEG F)       TWB(DEG F)    HOURS          TOWER
 57             52             24.82143      8
GPM             %GPM          CFM            TONS
 750            75             180000        100
CWS(DEG F)      CWR(DEG F)    DELTATCOND     DELTATTOWER    TOWERDUTY
 80                84.03179         4.031795         26.22048
5.973898E-02
PIPE D(FT)    Pipevelocity(FT/SEC)  REd           pipe frict
 .6666667       4.787051      369371.3       1.592428E-02
pipeL total     PHpipe             PHcond           PHtower
PHtotal(FT Water)
 666.6667       5.666439      5.105591       11              21.77203
PASSES          Condenservelocity
 2              2.900009
UACOND          LMTDCOND       NfISENT        NFTON          COND.TEMP
 893100.2        1.690421       .5164742       .6406521       84.4407
KWTONGUESS      KWTONMODEL     KWHBIN         KWHTOT
 .9074584        .9074562       2467.557       6497.896
HOURS           HOURSSUM
 24.82143        57.5
CHILLERKW        PUMPKW         FANKW          TOTALKW
 90.74583        4.342596       4.323931       99.41236


THE YEARLY TOTAL ($)   =      335188.1
THE PUMP ENERGY (KWH) =       9823.913
THE FAN ENERGY (KWH)   =      58278.78
THE CHILLER ENERGY  (KWH) =  337297.4
THE TOTALSYSTEM ENERGY (KWH) =               405400.2
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Thesis
R3755 Rice
c.1 Employing an effectiveness model for calculating cooling tower performance.